2018

Graph accessibility and comprehension for the blind: A challenge of its own kind

Ashley Nichole Nashleanas
Iowa State University

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Graph accessibility and comprehension for the blind:

A challenge of its own kind

by

Ashley Nichole Nashleanas

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education

Program of Study Committee:
Gary Phye, Co-major Professor
Anne Foegen, Co-major Professor
Christa Jackson, Co-major Professor
Eunjin Bahng
Shana Carpenter

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2018

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DEDICATION

Many come to mind when I consider to whom I would like to dedicate my dissertation. Unfortunately, not everyone on my list can fit into one double-spaced page. That said, I dedicate my dissertation to the individuals who have taken the time to oversee my journey from start to finish supporting me all throughout.

I dedicate my dissertation, first and foremost, to my family. Inevitably, with the pursuit of a doctoral degree comes a mixed bag of emotions – excitement about accomplishments along the way, nervousness about the unknown, and exhaustion from performing multiple steps at a time, day in and day out. My family listened as I spoke about my work. Some days, I expressed excitement and passion. Others, I expressed exhaustion. They supported me in talking openly about my graduate school experiences.

I also dedicate my work to my former swim coach, Paula Hamp, for imparting the qualities of character and resilience. I swam competitively for a number of years, performing against elite swimmers nationally and internationally. Paula instilled in me that giving up was never the answer. At the time I was competing, she provided the perfect combination of demonstrating stroke technique in a way I comprehended, constant reminders that the sky is the limit, and complementary remarks when I attained a goal. Paula inspired me to think that the sky is the limit with everything I do, and her involvement with my progress from a beginning swimmer to an American and world record holder gave me the level of motivation and confidence to pursue an academic degree at the highest level, regardless of the challenges that ensued. To Paula and all of the members of my family, I love you.
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I am fortunate to say that I have many colleagues that are worth acknowledging in the long yet exciting process of compiling a dissertation. To start, I would like to thank my co-major professors of my program of study committee, Dr. Gary Phye, Dr. Anne Foegen, and Dr. Christa Jackson, for their involvement from start to finish. As I was deciding which direction I wanted to take my schooling, Dr. Phye had talked with me about how my interests and skills would fit in with the research in the School of Education (SoE). Not only did he work with me throughout the application process, he also served as my co-advisor, providing wisdom that I took into account through the writing process and providing support on the lengthy, yet exciting, journey.

Anyone writing a dissertation can attest to its many challenges from designing the study, gathering sufficient data followed by hours of examination afterwards, to the iterative process of responding to multiple rounds of feedback for many chapters. Dr. Foegen has taken the time to provide multiple rounds of feedback for several parts of the dissertation while working with the challenges specific to my visual impairment.

My scholarly activities prior to graduate school in SoE did not involve research based interviews and observations. As a large part of educational research entails collection and analysis of interviews and observations, I needed to learn the trade in general and delve into the specific methodology that fit my own research interests. Limited access to multiple sources on research methodologies within a reasonable time frame added a challenging component to the already complex nature of qualitative research. Even with sufficient access to material, I absorb and articulate information in a unique manner. Taking advantage of the sources I could access at the time and working
with Dr. Jackson, I was able to apply the complexity of qualitative research. Dr. Jackson provided multiple rounds of feedback specific to the manuscript where I reported the results of the interviews and observation I conducted last year. Her words of encouragement with the areas of progress, and honesty with the gaps yet to be filled, gave me the confidence and motivation to conduct a qualitative case study in full and discuss the findings I came upon in the process.

In addition to acknowledging Drs. Phye, Foegen, and Jackson, I would like to thank committee members Dr. Eunjin Bahng and Dr. Shana Carpenter for their willingness and availability to provide me with guidance, wisdom, and support both within and external to the oral presentations required for a doctorate degree. All of my committee members are terrific resources, and I will have fond memories of our communication forever.

Dr. Reginald Stewart has provided me with an opportunity to delve into inclusion and diversity work as a potential avenue for employment, both during the dissertation process and after my dissertation has been completed. Not only has he provided me with insight into diversity and inclusion work, but I could share with him the steps I was taking to write the dissertation, and he was willing to listen and provide me with some interesting stories of his experiences while writing his own dissertation. We had plenty of good laughs and conversation, and I will miss the experience as I move on from Iowa State.

Also on the list, I would like to acknowledge all of the professors at the University of Notre Dame, where I earned my Bachelor of Science degree in Chemistry, my supervisors at the NASA centers where I interned, and Drs. Mark Gordon and
Theresa Windus (my co-advisers for the Master of Science degree I completed in the Department of Chemistry while at Iowa State). All contributed to my understanding of research centered on graph accessibility and comprehension for students with visual impairments, and the support their teachers provide, in the pursuit of my doctoral degree.

Sara Larkin (the mathematics consultant who provided the names of the participants for the study) was a wonderful resource. SVI and the teachers that serve them are few and far between, and Sara’s provision of participants’ contact information made it possible for me to connect with the individuals who can speak most accurately about the experiences of SVI with graphical information. In addition to providing participants’ contact information, Sara took time out of her schedule to speak with myself and Dr. Foegen about the educational backgrounds of the individuals in the survey sample. Sara’s insight was essential in helping us consider some of the statistical analyses we would be conducting at the time.

I also would like to show my appreciation to the individuals who chose to take part in my study. For one, teachers and students alike carved time out of their already busy schedules to respond to survey items and interview questions pertaining to their perceptions and experiences with graphs in high school mathematics courses. I especially thank the teacher and student who took part in the observation and follow-up interview session after the interviews I conducted initially. Their willingness to partake in my study in these ways provided me with a great deal of insight I can share with the community, and I learned about how SVI besides myself interact with graphical information along the way. The time my participants devoted, and the activities in which they engaged, speak volumes about their generosity.
Next, I would like to give thanks to my technical assistants, Jeffrey Rokkum, Justin Hallberg, and Marielle Machacek, for facilitating the process of formatting, both for myself and my co-advisers. Screen reading technology is not entirely compatible with software packages intended for statistical purposes. Jeff performed the needed statistical analyses and provided Dr. Phye, Dr. Foegen, and myself with the output in a timely manner. Many journal articles and books are not immediately accessible, and formatting manuscripts and PowerPoint presentations involve attention to detail that can be caught only with meticulous visual inspection. Justin and Marielle have been available to perform these tasks in a timely manner. They contributed by transforming material originally accessible to those with normal vision into something I could use, and vice versa. Performing these tasks reduced any communication barriers that otherwise would have come between myself and my colleagues and advisers.

To all of you, thank you again for your contributions. Your combined efforts have been the tools I used to pursue my passions.
The purpose of this dissertation is to explore graph accessibility and comprehension for students with visual impairments (SVI) in high school mathematics courses. The dissertation is comprised of three articles. In Paper One, I propose a conceptual framework to guide understanding around the approaches SVI use to access and comprehend graphical information. To do this, I draw from literature bases centered on the cognitive strategies individuals with visual impairments employ to understand spatial representations, tools and instruction to assist SVI in mathematics courses, and training of professionals serving SVI regarding their unique learning needs. In Paper Two, I report the results of a multistate survey on the perceptions of teachers of students with visual impairments (TVI) regarding the needs of SVI in high school mathematics courses to access and understand graphical information. Teacher perceptions suggested that (a) instructing SVI entails more than solely providing SVI with tactile graphics or verbal descriptions, (b) SVI access graphs in tactile form over sound or verbal descriptions, and (c) visual experience may affect the level of accuracy with which SVI perform graphing exercises. In Paper Three, I report the results of interviews with TVI and mathematics teachers regarding their perceptions of, and interviews with SVI regarding their experiences with, access to and comprehension of graphical information in high school mathematics courses. I also report the results of a classroom observation with a single SVI and the teachers that serve her needs to understand teacher support for SVI to access and comprehend graphical information. The results of this study suggest that (a) professionals who serve SVI with graphical information encompass more than mathematics teachers and TVI, (b) onset of visual experience carries weight when
considering the types of assistive technology and instruction SVI utilize to access and comprehend graphical information, and (c) each SVI has a unique set of approaches and challenges with graphs, even those with similar onsets of visual impairment. While these studies provide insight into graph access and comprehension for SVI in high school mathematics courses, they also point to areas where future research is needed.
CHAPTER 1: INTRODUCTION

Graphs are forms of imagery that students encounter in many disciplines associated with the physical sciences (Beichner, 1994; Hoban, Finlayson, & Nolan, 2013; Potgieter, Harding, & Engelbrecht, 2008), human sciences (Carpenter & Shah, 1998; Shah & Carpenter, 1995; Shah & Freedman, 2011), and history (Guthrie, Weber, & Kimmerly, 1993). Graphs are of particular importance in science, technology, engineering, and mathematics (STEM) (Asiala, Cottrill, & Schwingendorf, 1997; Friel, Bright, & Curcio, 2001; Leinhardt, Zoslavsky, & Stein, 1990). A large portion of the content in every STEM discipline is communicated through words and images that make use of vision (Moon, Todd, Morton, & Ivey, 2012). According to Cleveland, McGill, and McGill (1988) and Pinker (1990), humans attend more closely to graphs than they do to alternate forms of visual representation. Pinker, along with Cleveland et al., stressed that using graphs requires the process of relating variables to each other, and individuals start that process by grouping a graph’s components based on location and similarity of components, regardless of the type of graphs they use.

In order for students to succeed in any given area of STEM, it is imperative that students learn how to relate variables to one another through the use of graphs (Beichner, 1994; Hoban et al., 2013; Potgieter et al., 2008). Albeit students’ use of and familiarity with graphs is important in all STEM areas, my focus lies in the realms of graphs and mathematics, and in particular, students with visual impairments (SVI) in high school mathematics courses. I discuss the importance of graphing in mathematics and the issues students with normal vision encounter with graphing before I address the issues with SVI and graphing.
Capraro and Joffrion (2006) claimed that students do not have the skills necessary to start understanding algebraic functions and graphical representations until they enter high school. In many Algebra courses, teachers introduce algebraic functions in numeric form and their corresponding graphs (Aspinwall, 2002; Ellis, 2007, 2011; Even, 1998; Knuth, 2000; Leinhardt et al., 1990; Oehrtman, Carlson, & Thompson, 1997). These researchers assert that it is necessary for students to begin the journey of understanding graphical representations by learning how to use them in a mathematical context before they attempt to use graphs in the sciences, where content oftentimes builds upon concepts discussed in mathematics courses. Many times, however, students are introduced to algebraic functions and graphical representations separately rather than jointly. According to these researchers, teaching mathematics in this manner creates a situation in which students experience extreme difficulty in understanding that a function and its corresponding graphical representation are related to one another, so they struggle to develop the skills needed to understand how and why functions and graphs are related.

A substantial body of literature exists to advocate for the importance of understanding graphs for students without visual impairments. In comparison, a much smaller body of literature is available to suggest how students whose visual function is less than normal go through the process of using graphical information. Therefore, my focus is on the challenges SVI encounter regarding access to and comprehension of graphical information while in high school mathematics courses.

My interest in the topic of graph accessibility and comprehension for SVI in high school mathematics courses is in part driven by my experiences as a student with total and congenital blindness (e.g., total blindness from birth). I was not able to access or
understand spatial information through the use of vision, as all of my peers were able to do. However, I performed well enough to be considered at least at the level of the class average in all of the mathematics courses I have taken. In secondary mathematics courses, I received access to graphs in textbooks later than my peers with normal vision, as they were sometimes omitted from the braille version of textbooks I used. When the time at which I received access to spatial information lagged with regard to the rest of the class, I collaborated with my teachers to obtain tactile and verbal access so I would have knowledge of the material. I reviewed the material on my own after communicating with my teachers to ascertain that I understood the concepts, and addressed anything that was unclear with mathematics teachers or TVI as needed. However, I am aware that not all SVI are fortunate to have a terrific support system as I had while learning mathematics. Therefore, I am interested in understanding graph accessibility and comprehension from the voices of SVI, and the teachers who serve them, to create awareness of what is needed for SVI to be successful in high school mathematics courses.

**Issues regarding Accessibility and Comprehension of Graphical Information for SVI**

SVI obtain access to graphical information when they are provided with some form of assistive technology and instruction. I first discuss the challenges SVI encounter with graph accessibility by SVI in high school mathematics courses. Geraldine Scholl stated in 1969, “To a degree, visually handicapped children may be viewed not so much as having ‘educational methodology’ problems but rather ‘educational materials’ problems” (p. 223). While technology has advanced immensely since that time period, issues still exist with graph accessibility for SVI. In order to access spatial information in general, SVI utilize technology that capitalizes on the sensory modes available to them.
(Millar, 1994), and the same is true for graphical information. As a few examples, SVI use technologies that take advantage of touch (American Thermoform, 2016; ViewPlus Premium Braille Printers, 2016), sound (Ben-Tal, Berger, Cook, Daniels, & Scavone, 2002; Davison, 2013), and language (natural language assistive technologies, NLAT), (e.g., tools that produce textual descriptions of graphical representations) (Demir, Oliver, Schwartz, Elzer, Carberry, McCoy, & Chester, 2010; Ferres, Parush, Roberts, & Lindgaard, 2006).

The most common approach SVI use to access graphical information is through touch, but these technologies are costly and oftentimes require the use of someone with vision to construct the graphic (Ferres et al., 2006; Gerenazzo, Brayda, Bedin, Campus, & Avenzini, 2016). While tools used to relay graphical information through sound are downloadable and free of charge, Millar (1994), along with Gerenazzo et al. recommend that students refrain from using these tools until they have gained sufficient experience with tactile graphics. Similar to software that allows for graphs to be accessed through sound, software that allows for access through textual descriptions is downloadable and free of charge. However, Demir et al., along with Ferres, Lindgaard, Sumegi, and Tsuji (2013) showed that existing NLAT produce textual descriptions that are much more appropriate for use by individuals with a solid understanding of graphical information than they are for students who do not have a high level of familiarity with graphs.

While accessibility of graphical information for SVI involves assistive technology in part, it cannot be fully obtained without the implementation of instructional strategies provided by their teachers. Barth (1983), Quek & McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c) showed that SVI learn to use graphical information most
effectively when they are provided with systematic, hands-on instruction and clear language. Oftentimes, SVI do not receive proper instruction on how to use graphs due to gaps in teacher training. This is the case for teachers who serve needs unique to those with visual impairments, and high school mathematics teachers in the K12 system. According to McKenzie and Lewis (2008), SVI are served by two kinds of teachers: teachers of students with visual impairments (TVI) who are often itinerant, and paraprofessionals who serve students on a daily basis. TVI are licensed to teach SVI, whereas paraprofessionals are not. However, McKenzie and Lewis mentioned that TVI and paraprofessionals often take on similar responsibilities regarding material preparation and student instruction because of a shortage of qualified personnel to teach SVI.

The number of SVI in general education classrooms is increasing each year, with over 80% reported to be in classrooms learning alongside their sighted peers (Correa-Torres & Howell, 2004; National Federation of the Blind, 2016). The braille language comes in two forms, literary and Nemeth, and SVI access mathematical information through the Nemeth code used to represent mathematical notation rather than the literary braille code used for writing and reading text (American Foundation for the Blind, 2014). Teacher education programs do not train general educators to be competent in reading either form of braille (Kahn & Lewis, 2014; Rule, Stefanich, Boody, & Peiffer, 2011), and this puts general educators at a disadvantage as they attempt to communicate with SVI who use braille as their primary medium. In addition, there is a concern regarding the shortage of qualified personnel to work with SVI (Pogrund & Wibbenmeyer, 2008). DeMario, Lang, and Lian (1998), along with Kapperman and Sticken (2003), stressed
that the majority of TVI are not familiar with the Nemeth code nor the concepts SVI are learning in their upper level mathematics courses.

While access to graphical information can be problematic for SVI, comprehension of graphical information carries its own set of issues. According to Paivio (2013), individuals with normal vision comprehend spatial representations through many series of integrative processes that rely on prior knowledge. Millar (1994) asserted that individuals with visual impairments also comprehend information through processes that rely on prior knowledge, but not in the same way as individuals with normal vision do. While Paivio explained the comprehension process as series of integrative steps that happen immediately and in parallel for individuals with normal vision, Millar emphasized that individuals with visual impairments understand a spatial representation by first exploring it in a sequential manner (from left to right or from top to bottom) before they begin to understand what it is and how it relates to other spatial representations. But given the necessary tools, time, and instructional support, SVI are able to comprehend spatial information as well as individuals with normal vision.

Millar (1994) focused largely on children with total and congenital blindness and their understanding of spatial representations in general. How SVI comprehend graphical information requires further study. SVI are as capable as their peers with normal vision when learning mathematical concepts that involve imagery (Brahier, 2003; Fisher & Hartmann, 2005; Pritchard & Lamb, 2012; Quek & McNeill, 2006; Spindler, 2006). Further study is needed to determine whether SVI comprehend graphical information with the same level of accuracy as their peers with normal vision, and the processes by which SVI understand graphical information.
Pinker (1990), along with Shah and Carpenter (1998), showed that students with normal vision read and interpret graphs by giving attention to the function before they explore the referents (e.g., axis scales and labels). Barth (1983), Dick and Kubiak (1997), Ferres et al. (2013), and Quek and McNeill (2006) suggest that individuals with visual impairments interpret graphical information by focusing on the referents before attending to the function. For students with normal vision, Pinker, along with Leinhardt et al. (1990), asserted that graph comprehension requires both interpretation and construction. Regarding SVI, Barth (1983), along with Zebehazy and Wilton (2014b), mentioned similarly that graph comprehension involves interpretation and construction. I devote attention to what has been explored and the gaps in literature surrounding graph comprehension for SVI in mathematics courses, as well as teachers’ perceptions and students’ experiences I found while conducting my own studies, throughout the course of the dissertation.

In this dissertation, I intend to gain a deeper understanding of what graph accessibility and comprehension entail for SVI and the services their teachers provide. The dissertation consists of three papers. In the first paper (Chapter 2), I outline the development of a conceptual framework to guide understanding of how SVI in high school mathematics courses access and comprehend graphical information. I discuss literature surrounding the strategies individuals with visual impairments use to learn spatial information, as well as the gaps that exist regarding graph accessibility and comprehension for SVI. In the second paper (Chapter 3), I report the results of a survey from a multistate perspective that examines the perceptions of TVI regarding the needs and abilities of SVI for accessing and understanding graphical information. This study
received approval from the Iowa State University Human Subjects Research Office prior to data collection beginning. The approval letter is found in Appendix A. In the third paper (Chapter 4), I report the results of a qualitative inquiry examining the challenges SVI encounter with graphs in a classroom setting and the pedagogical and technological supports their teachers provide to access and understand graphs. This study received approval from the Iowa State University Human Subjects Research Office prior to data collection beginning. The approval letter is found in Appendix B. In the next section, I outline the terms and definitions related to the various aspects of blindness and the significance they carry regarding this small subset of the population.

**Terms and Definitions Specific to the Study**

The onset and level of visual impairment are characteristics that will influence the technology and teaching strategies a SVI may need in order to have a valuable educational experience. According to the National Federation of the Blind, “The statutory definition of ‘legally blind’ is that central visual acuity must be 20/200 or less in the better eye with the best possible correction or that the visual field must be 20 degrees or less” (“Learning with Blindness,” 2016, para. 1). However, there is not a comparable definition that encompasses the terms “visually impaired,” “low vision,” or “vision loss.” Only 18 percent of individuals with a visual impairment are totally blind, while the majority have some form of light perception (“Learning with Blindness,” 2016).

According to the Texas Council for Developmental Disabilities (n.d.), an individual’s onset of visual impairment can be congenital or adventitious. The Texas Council for Developmental Disabilities defines congenital visual impairment as an impairment that “occurs during fetal development, at birth or immediately following
birth; visual impairment is present before visual memory has been established” (para. 3) and adventitious visual impairment as one that “occurs after having normal vision either through a hereditary condition or trauma; visual memory may remain” (para. 3). I have defined these terms to stress that visual impairment is on a continuum, both in terms of the timing and severity with which an individual experiences it. Table 1 includes a list of terms and definitions I use frequently throughout the dissertation, as well as literature supporting those definitions.

**General Problem Statement and Central Research Question**

I am a doctoral candidate in educational psychology and happen to be totally and congenitally blind. On my journey to this point, I have had the opportunity to complete a bachelor’s degree and a master’s degree in chemistry. Researchers in the physical sciences communicate through graphs and other forms of imagery on a regular basis. All forms of imagery pose unique accessibility challenges for individuals with a visual disability. In addition, a literature gap exists regarding what is known about graph accessibility and comprehension for SVI. Therefore, I have chosen to center my dissertation on the following research question: What does graph accessibility and comprehension entail for SVI in secondary mathematics courses and the teachers who serve them? In order to answer this question, I have written three papers, each of which addresses the central question in a unique way.
Table 1. Terms and Definitions Regarding SVI in High School Mathematics Courses.

<table>
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<td>Graph</td>
<td>a pictorial representation that consists of labels, specifiers representing data values, and an overall framework</td>
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<td>Graph accessibility</td>
<td>the design of various products and services that allow for SVI to be aware of a graphical representation</td>
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<tr>
<td>Graph comprehension</td>
<td>a process that involves using information contained in graphical representations in a meaningful context, E.G., exploration, interpretation, and construction</td>
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<td>Paraprofessional</td>
<td>an educational worker who is not licensed to teach, but performs many duties both individually with students and organizationally in the classroom</td>
</tr>
<tr>
<td>Student with a visual impairment (SVI)</td>
<td>A student with “an impairment in vision that, even with correction, adversely affects a child's educational performance. The term includes both partial sight and blindness.” (Individuals with Disabilities Education Act, 2004)</td>
</tr>
<tr>
<td>Teacher of students with visual impairments (TVI)</td>
<td>“a licensed special education teacher who has received certification and specialized training, in meeting the educational needs of students who are blind or have visual impairments ages birth through 21” (Individuals with Disabilities Education Act, 2004)</td>
</tr>
<tr>
<td>Tactile Graphics</td>
<td>“a means of conveying non-textual information to people who are blind or visually impaired, and may include tactile representations of pictures, maps, graphs, diagrams, and other images” (PathsToLiteracy.org, 2018)</td>
</tr>
</tbody>
</table>

**Purpose and Significance of Dissertation**

Chapter 2 is a conceptual framework to guide understanding of how SVI access and comprehend graphical information. I address existing literature on the ways in which individuals with visual impairments understand and represent imagery and the gaps that exist in research regarding graph accessibility and comprehension for individuals with blindness and low vision. Millar (1994) theorized that individuals with visual disabilities
are not able to use vision as a means of accessing and understanding the information around them. Therefore, individuals with visual disabilities are forced to learn about their surroundings in a very different manner from their counterparts with vision. To my knowledge, Millar’s theory of spatial representation for children with blindness is the only theory to date that explains how individuals with blindness use touch and sound to access spatial information and encode what they have accessed into memory. However, Millar’s theory does not directly explain or predict how individuals with blindness and low vision should access and understand graphical information.

In Chapter 2, I use Millar’s (1994) theory of spatial representation to set the stage for how individuals with blindness and low vision, and SVI in particular, access and understand graphical information. SVI often have only limited access to graphs until they are exposed to technology that is able to produce graphs in accessible formats that utilize touch, sound, or a combination thereof. After they have had the opportunity to access graphs, they are likely to use sequential strategies that accommodate to touch and sound to understand the importance of graphs for solving mathematical problems.

As much as eighty percent of the information a person without a visual impairment learns is through vision, and the remaining sensory channels do not compensate for absence of sight when attempting to accomplish tasks that involve spatial learning (Texas Council for Developmental Disabilities, n.d.). For individuals with visual impairments, the absence of full visual experience creates challenging situations when attempting to understand visual representations such as graphs. To compensate for SVI lack of vision, I utilize literature that focuses on SVI and graphing (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c) to
articulate the strategies SVI in high school courses will likely use to comprehend graphical information, and how the learning strategies used by individuals with visual impairments differ from those exhibited by individuals with normal vision. The contribution of Chapter 2 to the dissertation is to describe existing knowledge about graph comprehension for individuals with normal vision and to identify gaps in the current literature about what graph accessibility and comprehension entail, both for SVI in high school mathematics courses and the teachers that serve them.

In Chapter 3, I report the results of a survey with a multistate perspective on graph accessibility and comprehension for SVI from the perspectives of thirty-four TVI. The sample was split into TVI with and without formal educational preparation in mathematics. The purpose of Chapter 3 is to (a) determine if significant differences exist between responses given by TVI with and without formal preparation in mathematics as they perceive the teaching strategies and technological resources SVI need to access and comprehend graphical information, and (b) determine which characteristics surrounding TVI experience with teaching SVI influence teacher responses.

Due to the uniqueness of the strategies SVI use to access and learn spatial information (Millar, 1994), and graphical information in particular, (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c), learning how to instruct SVI effectively about mathematical concepts will require more time and experience compared to teaching those with normal vision. Chapter 3 contributes to the dissertation by filling an existing gap in the literature, as it provides a national picture of the perceptions of TVI on the pedagogies and technologies used to support SVI in accessing and comprehending graphs.
In Chapter 4, I used qualitative methods to explore in greater depth the issues of graph accessibility and comprehension for SVI in high school mathematics courses. This paper reports the results of a study examining (a) teachers’ perceptions of how they support SVI to learn graphical information, (b) the ways in which SVI in high school mathematics courses learn graphical information, and (c) the ways in which a mathematics educator supports a SVI to learn graphical information. In order to gain a deeper understanding of teachers’ perceptions and students’ experiences with graphical information, I conducted initial interviews with four TVI, two mathematics educators, and three SVI, as well as a classroom observation with one mathematics educator and one SVI and one follow-up interview with the same educator and student who participated in the observation. Chapter 4 contributes to the dissertation by portraying the unique challenges SVI encounter when attempting to access and comprehend graphs in a classroom setting, along with the instructional practices and technological resources teachers use to support their learning needs.

Conclusion

The overarching question for the dissertation is: What does graph accessibility and comprehension entail for SVI in secondary mathematics courses and the teachers who serve them? In this chapter, I have introduced three papers I have developed for the dissertation. In the remaining chapters, I provide a more detailed account of the results of the studies I conducted, and the contributions my studies bring to the existing bodies of literature on SVI and graphing in high school mathematics courses.
CHAPTER 2. GRAPH ACCESSIBILITY AND COMPREHENSION FOR STUDENTS WITH VISUAL IMPAIRMENTS: A CONCEPTUAL FRAMEWORK

Ashley Nashleanas

Publication Status: Not yet submitted

Abstract

Theoretical underpinnings of understanding spatial information have been published, both for individuals with visual impairments (VI) and individuals with normal vision. While there is literature to explain the mechanisms by which individuals with normal vision learn graphical information, comparable work does not exist for individuals with VI. In this article, I bring together bodies of literature to propose a conceptual framework specific to graph accessibility and comprehension for students with visual impairments (SVI) in high school mathematics courses. I first outline the literature published on spatial understanding and graph comprehension for individuals with normal vision. I then discuss the gaps in the theoretical and practitioner-centered literature regarding graph accessibility and comprehension for SVI. Next, I describe and elaborate on the conceptual framework to explain graph accessibility and comprehension for SVI in high school mathematics courses by couching the framework in the published literature and demonstrating where the framework could fill existing literature gaps. Finally, I discuss implications for future research in the areas of graph accessibility and comprehension for SVI in high school mathematics courses.

Keywords: students with visual impairments, graphs, accessibility, comprehension
Graph Accessibility and Comprehension for Students with Visual Impairments: A Conceptual Framework

Graph Comprehension: Issues for Students with Visual Impairments

Students with visual impairments (SVI) make up less than two percent of the total student population in the United States (National Federation of the Blind, 2016). The low-incidence nature of SVI in educational settings, in combination with the learning challenges associated with a visual impairment, create a unique situation for SVI in high school mathematics courses. Graphs are an integral part of mathematics, and SVI encounter barriers that are not well understood by the general education community. Theory and models have been proposed to explain the ways in which students with normal vision learn to use graphs, but no such theory exists to explain graph comprehension for SVI. The purpose of this paper is to propose a model in the form of a conceptual framework that can be used to explain how SVI likely access and comprehend graphical information in high school mathematics courses.

Access to and Comprehension of Spatial Information for Individuals with Normal Vision

Individuals with normal vision access and understand the world around them through the use of vision in conjunction with touch, sound, taste, and smell. According to Paivio (2013), numerous theorists have suggested that the human mind was not fit to process verbal and nonverbal information at the same time. Paivio argued that previous theorists had not considered the idea that the human mind is fit for encoding both verbal and nonverbal information, and asserted that the mind processes both forms simultaneously as a result of dual encoding. I elaborate on Paivio’s Theory of Dual
Encoding as the most recent and comprehensive account of how humans with normal vision access and learn information.

**Dual Coding Theory: Paivio’s Foundation**

We, as human beings, and all things in our surroundings, occupy a given amount of space. We use our senses to gather information and to comprehend the importance of certain objects around us. Paivio (2013) proposed Dual Coding Theory (DCT) to account for the ways in which we gather information through encoding processes that complement one another. According to Paivio, DCT explains the mechanisms by which we connect previously encoded and incoming information to allow for comprehension to take place. Unlike theories prior to DCT, Leakey and Lewin (as cited in Paivio, 2013) claimed that the verbal and nonverbal memory systems cannot work in conjunction with one another. Paivio proposed the theory of dual encoding in order to consider the interplay of the verbal and nonverbal memory systems.

As Paivio (2013) explained, each system dominates in a specific domain. Using map reading as an example, the verbal system deals primarily with language and speech, thus dominating in tasks such as reading words or phrases on a map. The nonverbal system is used to deal primarily with the encoding of imagery, as an example, encoding visual cues such as shapes and lines on the same map into memory. According to the DCT approach, verbal information is encoded linearly as strings of words and phrases, while nonverbal information is encoded in a much more complex, web-like fashion to form two-dimensional and three-dimensional images.

Visible shapes and lines are connected to one another to form a two-dimensional representation in the mind for following paths, and the words and phrases serve as flags
to give meaning to the individual lines and shapes used to form those paths and to the map as a whole. The words on the map do not carry any meaning on their own, and the same is true for the shapes and lines that create the image of the map. To use all of the information on the map for the purpose of navigating from one point to another, verbal and nonverbal systems work in conjunction with one another to connect the words and shapes in a way that associates language and imagery into a meaningful representation, thus making it possible for one to use verbal and nonverbal cues simultaneously when traveling. Regardless of the amount or type of information that is encoded into memory, retention of information previously encoded into long-term memory and the connections of information in long-term memory to new information coming through short-term memory cannot take place unless dual encoding is involved.

According to Paivio's (2013) DCT approach, three distinct yet equally important events need to take place in order that one becomes skilled in using spatial information: access, memory, and comprehension. Access to spatial information takes place when one or more of the senses becomes activated by a single stimulus or a set of stimuli, respectively. At the time of activation, the verbal and nonverbal systems work hand-in-hand to encode the stimulus or stimuli into short-term memory, and repetition of the activation results in information being encoded into long-term memory.

**Baddeley’s Working Memory**

Baddeley's (2015) working memory model provides a more detailed account of the roles of short-term, long-term, and working memory in the encoding process. Short-term memory is activated when a stimulus first enters the system. Working memory is responsible for the organization of information that has come through short-term memory
into verbal and nonverbal chunks, and those chunks are stored later in long-term memory. The episodic buffer serves as the link between working memory and long-term memory since it is used to store multiple chunks of verbal and nonverbal information that are retrieved from long-term memory into working memory, and these chunks are composed of events and situations experienced in the past and at the present time.

Paivio (2013) and Baddeley (2015) discussed the means by which individuals with normal vision access and understand spatial information. Pinker (1990) discussed the means by which students comprehend graphs as a specific form of spatial information. Similar to other visual representations such as maps, graphs contain symbols that are encoded as verbal text strings (title and axis labels) as well as symbols that are encoded as nonverbal images (numbers, tick marks, and graph shape). Pinker, along with Balchin and Coleman (1966); Friel, Bright, and Curcio (2001); and Kosslyn (1989) asserted that graphs are more difficult to comprehend than are maps and other two-dimensional spatial representations. Graphs are used to depict relationships between quantities of two or more related variables, whereas maps depict the relationship of a two-dimensional space without the constraint that quantities must be related to one another.

Pinker’s Theory

Pinker (1990) proposed a theory of graph comprehension to account for how students with normal vision read and interpret graphs. He contended that an experienced graph user will read the title, focus on the display of the function, and finally relate the functional shape of the graph to referents such as axis labels and scales. Carpenter and Shah (1998) reported results that parallel Pinker's proposition. They used eye-tracking
technology to investigate gaze patterns of upper-level undergraduate students as they interpreted graphical information. They found that each undergraduate started with the title, then gazed at the function, and then at the axis labels and scales. Pinker, along with Carpenter and Shah, claimed that graph users focused on the functional shape before focusing on the referents (e.g., axis labels and scales), because the display of the function in a graph visually stands out more than any other feature. Paivio (2013), Pinker, and Carpenter and Shah maintained that individuals with normal vision explore imagery in a holistic manner, in which one immediately integrates multiple pieces of information to understand the larger picture, then breaks the larger picture into its components. The existing research provides a basis for how individuals with normal vision learn about graphical information, but it does not address the needs of students with visual impairments.

**Theories and Instructional Practices Regarding Spatial Understanding for SVI**

**Millar’s Theory of Understanding Spatial Representation**

To my knowledge, no theoretical basis exists for the behaviors of students with visual impairments (SVI) as they comprehend graphical information. Millar (1994) proposed a theory of understanding and representing space for children with total congenital blindness; her focus was on tactile small-scale and large-scale spatial representations as environmental cues for learning the layout of an environment or traveling a route from a starting point to an endpoint. Millar stressed that children with total congenital blindness use vastly different techniques to explore their environments relative to their counterparts without visual impairments (VI).

Contrary to DCT (Paivio, 2013), Millar (1994) claimed that children with total congenital blindness explore their environments in a sequential manner, as they utilize
the modalities of touch and sound to understand their environment in terms of individual components. They then use past and present experiences to connect individual pieces to one another to understand the environment. Millar (1994) stated that individuals with total congenital blindness comprehend spatial information in a different manner than those with vision, because individuals with blindness encounter unique challenges when they attempt to access spatial information. She emphasized that the modalities of touch and sound allow only for the uptake of information in a sequential manner. While vision is not the only modality by which individuals with normal vision encode information, vision provides a far greater amount of information at one time than would a combination of any of the nonvisual senses. Although Millar acknowledged that individuals with blindness can and do encode information with touch, sound, smell, and taste, she focused on their encoding and understanding of spatial information through movement and touch. Individuals with sight use their vision to access multiple sources of information in a spontaneous, rapid, and redundant fashion. The act of accessing information with movement and touch cannot be accomplished with the same spontaneity, rapidity, or redundancy as it can be with vision. Therefore, individuals with sight both access and encode information in terms of a general layout in which multiple activities are occurring simultaneously; in contrast, individuals with blindness access and encode the same spatial information in a route-like fashion in which one activity occurs at a time.

**Instructional Practices for Mathematics**

The distinctive mechanisms by which individuals with VI access and comprehend spatial information call for special technological tools and instructional strategies. In the case of accessing and comprehending mathematical concepts generally, and graphs in
particular, researchers have discussed various tools and means of instruction by which SVI learn mathematical concepts (Dick & Kubiak, 1997; Fisher & Hartman, 2005; Pritchard & Lamb, 2012; Quek & McNeill, 2006; Spindler, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c). For example, Fisher and Hartmann promoted the use of the abacus as a tool for performing arithmetic calculations. Beads of a particular shape and size represented whole numbers, while beads of another shape or size represent decimal numbers. Pritchard and Lamb discussed the tools and strategies for teaching geometry to a student with blindness. During a unit on finding the area and perimeter of solids, the instructor used a combination of a geoboard (a graphing tool for SVI), a pencil as the axis of rotation, shapes made from cardstock, and solid shapes as manipulatives to assist the student with finding surface areas and perimeters of solid objects of rotation. With regard to teaching graphical information, Dick and Kubiak, along with Quek and McNeill, emphasized the combination of raised line drawings, hands-on instruction, and sufficient verbiage. They asserted that it is vital for instructors to assist students in tracing the tactile graphic with their fingers as they verbalize each component with terminology such as “x-axis,” “y-axis,” and “function.” Zebehazy and Wilton (2014a; 2014b; 2014c) studied the quality and importance of graph instruction for SVI from the perspectives of TVI and SVI. The teachers in Zebehazy and Wilton (2014a) suggested that SVI needed direct, hands-on instruction to explore tactile graphics. The teachers in Zebehazy and Wilton (2014b), and the students in Zebehazy and Wilton (2014c), shared that SVI learn to explore tactile graphics in a piecewise manner, starting
Ensuring that SVI have opportunities to develop competence with graphical information poses a significant challenge. According to Kahn and Lewis (2014) and Rule, Stefanich, Boody, and Peiffer (2011), general educators are likely to have little to no experience with the needs of SVI. Many teachers of students with visual impairments (TVI) are known as itinerant teachers, as they work with SVI from multiple school districts (Correa-Torres & Howell, 2004). Though braille itinerant teachers are familiar with the needs of SVI, many do not have enough expertise in mathematics to assist SVI in learning the material (Pritchard & Lamb, 2012). While there is a small body of literature to support that SVI access and comprehend graphs in different manners than their peers with vision, (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c), there have been no conceptual or theoretical frameworks to account for the methods by which SVI access and comprehend graphs.

In the next section, I introduce a conceptual framework to suggest that SVI access and understand graphical information in a vastly different manner than do individuals without a visual disability. I interweave aspects of Millar’s (1994) theory and literature that addresses the learning of graphs for SVI, (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c), to identify challenges, strategies and gaps in the current literature regarding graph accessibility and comprehension for SVI in high school mathematics courses.

**Conceptual Framework for Accessibility and Comprehension of Graphical Information for SVI**

**Textual Description of Conceptual Framework Diagram**

Figure 1 displays the conceptual framework I developed to explain how SVI may access and comprehend graphical information. In order to make the conceptual framework
diagram most accessible to individuals with visual impairments, I provide an extended description that narrates the figure. I describe the figure from bottom to top for the purposes of paralleling Millar’s (1994) findings that children with blindness begin the exploration process in an egocentric (e.g., personally-referenced) fashion, in which they are likely to start at the point nearest the body and proceed upward and outward from that point.

*Figure* 1. Conceptual Framework of Graph Accessibility and Comprehension by SVI in High School Mathematics Courses.
The conceptual framework contains seven circles connected to one another. The straight line segments indicate that each component is necessary for a process to occur. The straight arrows indicate the occurrence of one event before another, and the curved arrows indicate events that occur in a repetitive fashion. Note that I selected the sizes of the circles to reflect the respective salience of the components of the conceptual framework.

I labeled the bottom circle accessibility. Accessibility is composed of assistive technology, instructional strategies, and the training teachers receive to instruct SVI. Within accessibility, the left circle is assistive technology, the right circle is instructional strategies, and the circle located slightly above these two is training. Assistive technology, instructional strategies, and training are of equal size and connected to each other by straight line segments. While SVI use assistive technology to touch and hear graphical information, SVI will be able to utilize assistive technology successfully only when TVI are able to provide instruction that accommodates to their unique learning strategies. It is necessary for teachers to receive training in the areas of assistive technology and instructional strategies in order to teach SVI correctly with regard to graphical information. I define training as the knowledge and skills teachers acquire when earning their degrees as educators along with subsequent professional development opportunities. Professional development for TVI is state-specific (Suvak, 2004). For example, Colorado and Louisiana provide professional development opportunities that include courses, conferences, and workshops which focus on specific aspects of teaching individuals with visual impairments (Colorado Department of Education, 2017; Professional Development and Research Institute on Blindness, 2018).
Accessibility is connected to sequential encoding by a straight, single-headed arrow to indicate that, for SVI, accessibility to proper technologies and pedagogies triggers encoding of that information into memory in a sequential manner. Directly to the left of sequential encoding is a circle labeled integration. Sequential encoding and integration are connected through a curved, double-headed arrow. Sequential encoding takes place before integration does. However, Millar (1994) showed that as students become more experienced with sequential encoding, they gain more experience with integration, and both steps take place more quickly as students gain experience encoding spatial information.

Above sequential encoding and integration is the largest circle in the diagram, labeled comprehension. Integration is connected to comprehension through a curved, double-headed arrow to indicate that, with more experience in both integration and comprehension, both components happen more quickly and efficiently. Comprehension connects back to sequential encoding through a single-headed arrow to indicate that comprehension informs future learning through sequential encoding for SVI as they learn to use graphical information. I expand further on what I mean by comprehension in the sections to come.

In the next section, I explain assistive technology and instructional strategies that make accessibility of graphical information possible for SVI, as well as the barriers associated with utilizing them. I then discuss what is known about graph comprehension for individuals with visual impairments and the gaps that still exist. I conclude the paper with implications for how the conceptual framework can be utilized to gain a deeper
understanding of how SVI access and comprehend graphical information in secondary mathematics courses.

**Graph Accessibility Requires Assistive Technology, Instructional Strategies, and Teacher Training**

I constructed *accessibility* as a larger circle encompassing *training, assistive technology*, and *instructional strategies* to symbolize that accessibility requires the exposure of teachers to appropriate training in assistive technology and instructional strategies. As Geraldine Scholl (1969) stated regarding the cognitive abilities of SVI in conjunction with the importance of accessibility to educational material for learning, “To a degree, visually handicapped children may be viewed not so much as having ‘educational methodology’ problems but rather ‘educational materials’ problems” (p. 223). Over forty years have passed since Scholl stressed the idea that limited accessibility to visually oriented material contributes to many of the problems SVI encounter when in an educational setting. Although many assistive technologies have improved since Scholl made her point, SVI still face challenges to accessibility of graphical information in science, technology, engineering, and mathematics (STEM). For SVI, access to graphs is possible through tactile means in the form of printers that generate raised images (American Printing House of the Blind, 2016; American Thermoform, 2016; ViewPlus Premium Braille Printers, 2016), sonification (Ben-Tal, Berger, Cook, Daniels, & Scavone, 2002; Davison, 2013), natural language assistive technology (Chelin, Kosseim, & Radhakrishnan, 2006; Demir, Oliver, Schwartz, Elzer, Carberry, McCoy, & Chester, 2010; Ferres, Parush, Roberts, & Lindgaard, 2006), and E-ink (Beal & Rosenblum, 2015; Gorlewicz, Burgner, Withrow, & Webster, 2014). Each of the above types of assistive
technology carries its own set of advantages and disadvantages for the user, which are described below.

**Accessibility Requires Assistive Technology**

In the conceptual framework, I define *assistive technology* as any vehicle that generates accessible graphical information. High quality tactile representations of graphs are generated via braille embossers such as those belonging to the Tiger series (American Thermoform, 2016; ViewPlus Premium Braille Printers, 2016). Having access to machines is advantageous, because they produce tactile images that are easy for SVI to explore with their hands, and the printer paper is sturdy enough for the image to keep intact for a decent time period. However, these machines may cost thousands of dollars, and assistance from an individual with vision is necessary to produce the printed image into its tactile form. Raised line drawing tools such as the Crafty Graphics Toolkit and the Draftsman Drawing Toolkit produced by the American Printing House of the Blind (2016) are much more reasonable in price and more portable than a braille embosser. Like braille embossers, raised line drawing kits also require the assistance of an individual with vision.

Sonification, or mapping data to sound parameters, is a technique that became viewed as potentially beneficial for SVI to use as a means for accessing graphical data at the beginning of the twenty-first century (Ben-Tal et al., 2002; Brewster & Murray-Smith, 2000). Sonification tools are free to download, and the technique is becoming more popular as a complementary or alternative method to accessing graphical information through touch (Davison, 2013). However, Millar (1994) pointed out that touch is the primary sense for understanding spatial representations. Sound alone cannot
substitute for the configurational information touch and movement provide about objects in an environment and their spatial relation to one another. In agreement with Millar's argument that characteristics of a spatial layout are encoded primarily through touch and movement rather than sound, McGooEin and Brewster (2006) and Davison (2013) claimed that students who plan to use sonification for accessing graphical information must be proficient in the use of tactile graphs before they consider sonification. Only then will SVI be able to understand the meaning of the changes in pitch, volume, and other parameters associated with sonification as they relate to what they have learned about graphs.

The term E-Ink is used to encompass assistive technologies such as the Talking Tactile Tablet (Gorlewicz et al., 2014) and the iPad (Beal & Rosenblum, 2015). These assistive technologies are used by students with normal vision in mainstream mathematics and science classes and could be of great benefit for SVI to access graphical information along with their peers in the same classes. Talking tactile tablets and iPads are categorized as E-ink because they have screens whose components become activated by the touch of a fingertip. Both products provide tactile and auditory information as they vibrate and speak when a student touches certain locations on the screen. However, Gorlewicz et al. and Beal and Rosenblum agree that there is not enough literature published on E-Ink technologies to compare the quality of information students are receiving or the product usability these technologies provide.

Natural language assistive technologies (NLAT) generate textual descriptions of visually oriented information (Chelin et al., 2006). NLAT are free to download and can be used with screen-reading technologies such as Window-Eyes (GW Micro, 2016), Jaws
for Windows, (Freedom Scientific, 2016), and VoiceOver for Mac (VoiceOver, 2016). Whereas screen-reading technologies can parse only information contained in graph captions, NLAT such as Interactive SIGHT (Demir et al., 2010) and iGraph-LITE (Ferres, Lindgaard, & Sumegi, 2010; Ferres, Lindgaard, Sumegi, & Tsuji, 2013) provide more information than that contained in captions, because they generate descriptions that give specific information about the graph, such as the title, graph type, and axis information as units and scales. However, Interactive SIGHT and iGraph-LITE provide descriptions using language intended for technical audiences with much more knowledge of graphs than would be exhibited by students who are enrolled in secondary mathematics courses. Even if the language contained in NLAT descriptions was suited to an audience of students in secondary mathematics courses, Millar’s (1994) theory asserts that it is likely that these students would need to be familiar with tactile representations of graphs in order to relate what they have learned through touch and movement to textual information within the descriptions. All of the technologies described here offer increased accessibility for SVI, but their value will not be optimized without effective pedagogical considerations.

**Accessibility Requires Instructional Strategies**

In the conceptual framework, I define *instructional strategies* as pedagogical techniques teachers use with graphs that have been generated through appropriate assistive technology. Barth (1983) reported the results of a study on the development and testing of the Tangible Graphing Program, an instructional program intended to improve tactile graph interpretation for SVI. The program instructed 60 braille reading students ranging from grade five to grade ten to start by learning the textures of points and single lines, then to recognize grids, relationships between two or more lines within the grid,
and finally concepts such as slope in the case of line graphs, and other types of graphs. The program was created based on a sequential learning strategy because SVI in the program had no prior experience in graph reading or interpretation tasks. From pretest to post-test, Barth reported significant improvement in graph reading and interpretation skills for those in the treatment group who received step-by-step, systematic instruction; whereas, no significant improvement was reported for those in the control group. These findings are important for instructors of SVI. Millar (1994) stressed that step-by-step, systematic exploration is vital, especially for SVI as they learn to read and draw maps. Likewise, Barth, along with Zebehazy and Wilton (2014b; 2014c) showed that step-by-step, systematic exploration is essential for SVI to read and interpret tactile graphs successfully.

Ferres et al. (2013) conducted a field study in which a statistician with total blindness described his method of obtaining information in order to provide researchers with information about how to order the graph feature text descriptions in a NLAT system. The statistician stated that he preferred the title first, then the graph type, (e.g., line graph), then an examination of the $x$-axis referents and $y$-axis referents, and finally the general shape. Though the participants in the Barth (1983) and Ferres et al. (2013) studies differed in age and experience with graphs, the results were consistent in that graph users with VI tended to prefer exploration of the axes and their referents before understanding the shape of the function. This finding is in opposition to Pinker's (1990) theory and Carpenter and Shah's (1998) eye-tracking results, which showed students with normal vision examined the shape of the function before they examined the axis information. Based on Millar's (1994) discussion of how children with blindness tend to
draw a two-dimensional representation initially as a set of unconnected lines, and use a step-by-step process to make connections between each line to get the final portrait, it is likely that SVI examine graphs in a similar manner to how they draw two-dimensional representations.

In addition to the ways in which the literature suggests SVI organize graphical information, language plays an important role in the process of understanding mathematics in general (McCallister & Kennedy, 2001; Pritchard & Lamb, 2012; Spindler, 2006) and graphs in particular (Dick & Kubiak, 1997; Quek & McNeill, 2006). For example, Dick and Kubiak stressed that instructors must avoid vague language such as “up,” “down,” “here,” and “there” when describing graphical representations; more specific verbiage about the features of the graph would be beneficial to students with sight and SVI alike. Quek and McNeill agreed with Dick and Kubiak that vague language to explain mathematical concepts is inappropriate for learners with VI, but they stressed that individuals without VI are not disadvantaged when vague language is used, because they are able to attend to the movement of the instructor's gestures relative to multiple visual images at a time. Quek and McNeill described the language and gestures a high school mathematics instructor used to explain a sine wave to the students without VI, and the vastly different techniques she employed as she discussed the sine wave with a group of SVI. For SVI, the instructor used a sequential strategy as she watched each student find one point at a time on a braille graph and guided the student's hand to the correct position if he/she was in the incorrect spot. She also specified the values at each maximum, minimum, and midpoint, even though each student had access to this
information on the graph, and watched students as they moved their hands to the locations she specified.

**Issues with Teacher Training**

TVI receive training that is vastly different from the training general educators receive. For example, TVI are trained to serve SVI, though not in specific topic areas (Pogrund & Wibbenmeyer, 2008). These teachers have a wide variety of responsibilities to which they attend regarding their students, and they acquire knowledge of their responsibilities through professional development classes as requirements for the completion of the TVI credential. Their responsibilities may include, but not be limited to, teaching students how to travel safely and independently, academic subjects as mathematics and language arts, knowledge of where to order braille and large-print resources, knowledge of assistive technology, and the ability to negotiate with parents and general classroom teachers as to the types of resources their students need for similar access to materials as their peers with normal vision (Suvak, 2004). Demario, Lang, and Lian (1998) and Kapperman and Sticken (2003) reported that well over 50% of TVI do not receive adequate training in the Nemeth code (the code for braille mathematical notation), and thus, do not have the knowledge base to teach their students to use the Nemeth code or develop a solid mathematics foundation.

High school mathematics teachers are trained to teach mathematics, but training to address the needs of students with low-incidence disabilities is rarely included in teacher education programs (Kahn & Lewis, 2014; Rule et al., 2011). Therefore, general educators are forced to acquire knowledge of the needs of students with visual impairments at the time they find themselves with SVI in their classes by learning about
the needs of SVI through a combination of discussion with and observation of SVI and TVI (Pritchard & Lamb, 2012).

**Timing and Accessibility**

Assistant technology, instructional strategies, and teacher training are required for students to receive accessibility to graphical information. In addition, it is important to consider the timing at which SVI receive access to graphical information relative to their peers with normal vision. Because the verbal and nonverbal memory systems work together for the encoding of spatial information, it is meant to be accessed through multiple senses at once rather than access occurring through individual senses at separate times, as Paivio (2013) discussed for individuals with normal vision and Millar (1994) argued for individuals with visual impairments. Millar (1994) further stressed that timing of access to spatial information may be even more crucial to individuals with visual impairments than it is for individuals with normal vision. Because individuals with visual impairments absorb spatial information through touch and sound, which do not provide the amount and redundancy of information vision does, individuals with visual impairments cannot rely as heavily as their peers with normal vision on prior experiences.

Regarding SVI and timing of access to graphical information in mathematics courses, I use a similar line of argument as Millar (1994). Timing of access to graphical information is especially crucial for SVI to their limited experiences with spatial information relative to their sighted peers. Dick and Kubiak (1997) and Quek and McNeill (2006) emphasized that poor timing of access to graphical information for SVI can be detrimental to their learning experiences. Pritchard and Lamb (2012) provided an example in which their student with total blindness was provided access to the material well behind the time at which the material was covered in class. While the student
succeeded in geometry, her time was spent taking notes in braille on material she did not have at her avail, then accessing and understanding tactile representations seen weeks ago by her peers with normal vision. Meanwhile, her peers proceeded according to the teacher’s expectations of when and how to understand geometry concepts, because they had access to the material at all times through the use of vision. Dick and Kubiak (1997), Pritchard and Lamb (2012), and Quek and McNeill (2006) agree that the learning experiences of graphical information for SVI will improve dramatically only if they receive access to graphical information in a similar time frame relative to their peers with normal vision. To discuss accessibility of graphical information for SVI, I summarized literature that spans across assistive technology, instructional strategies, and teacher training. In the next section, I discuss how comprehension takes place for individuals with normal vision, and the gaps that exist for graph comprehension regarding SVI.

**Comprehension of Graphical Information for SVI**

Despite the importance of comprehending graphical information, to my knowledge no theoretical basis exists to account for the mechanism by which SVI understand graphs. To consider a mechanism by which SVI may comprehend graphs in high school mathematics courses, I first discuss Paivio’s (2013) work on the processes involved with comprehension along with Millar’s (1994) theory of comprehension of spatial information.

Although access to and memory of situations are important in the learning process, access and memory alone cannot ensure that comprehension takes place (Paivio, 2013). Paivio explained the complex task of assessing whether comprehension takes place by stating, “To be studied, comprehension needs to be operationalized, and, like
other psychological concepts, there is no single ‘true’ measure or procedure that can do
the job, for there is no all-or-none ‘click’ of comprehension” (p. 105). Paivio emphasized
that, for comprehension within human beings to be assessed, a multitude of studies must
be conducted, then compared and contrasted, even when assessing comprehension of a
concept on a shallow level. Paivio explained that comprehension requires a combination
of encoding a multitude of events into memory and integration of particular events with
one another. He pointed out that making meaning of an event or situation is based solely
on the experiences of the individual. Thus, a group of individuals may comprehend the
same scenario equally well, yet use a distinct set of words or images to make meaning of
the scenario.

Paivio (2013) asserted that learning is an assimilation of past and present events
experienced from multiple senses. Thus, the number and type of past situations an
individual has experienced will influence the way in which that individual comprehends a
present situation. He referred to numerous studies to show a significant improvement in
the comprehensibility of texts in which words and phrases were accompanied by images
on a repetitive basis, and vice versa, as opposed to text or images alone, thus emphasizing
the point that making meaning of spatial information requires repetition and integration
of information using multiple modalities. Paivio’s theory of dual encoding is based on
how an individual with vision accesses and comprehends spatial information. His theory
does not account for the unique learning strategies of individuals with visual impairments
and the challenges associated with these learning strategies.
Paivio (2013) and Millar (1994) asserted that multiple modalities are used to encode spatial information, and learning how to use spatial information in an appropriate way takes place more quickly and easily with experience and encoding of the information through multiple channels at the same time. However, Millar accounted for the sequential encoding strategies by which individuals with blindness encode information as the step prior to integration. Millar emphasized that, even when individuals with blindness are able to access the same information through touch and movement as their peers do with vision, the encoding mechanisms associated with touch and movement are rather different than the encoding mechanisms associated with vision. She stressed the differences between touch and vision for encoding spatial information when she stated:

...the range and type of information needed for shape recognition differ among different sizes and types of objects. That needs to be made explicit, especially because the differences involve the availability of reference cues. The point is that the description of processes in tactual recognition differs for different types and sizes of shape, in a way in which that is not true of visual shapes. In vision, differences in size and depth are not a major problem. By contrast, studies of tactual recognition show many apparent contradictions if we assume that precisely the same description applies in the case of three-dimensional objects that can be handled, raised dot patterns and flat objects that are felt passively from being placed on the skin (p. 90).

Tactual cues on which individuals with visual impairments rely are limited in comparison to visual reference cues. Individuals with visual impairments are only able to encode incoming tactile information in reference to their bodies and not to external
reference frames when they use movement coding. Millar (1994) explained that encoding by touch and movement for individuals with VI requires systematic exploration. Therefore, encoding of any spatial representation by touch and movement is performed by a sequence of steps, where one step must be completed before another begins. Millar illustrated, through her own work and the work of other scholars, that individuals with blindness cannot access the same type or amount of information as their peers with vision can access immediately at a glance. Individuals with blindness exhibit strategies in which their hands move from the point nearest the body to the point furthest away from the body before they understand its shape. Thus, individuals with blindness lag behind in learning to understand representations their peers without VI are able to understand within a brief time period.

According to Millar (1994), individuals with and without vision rely on prior knowledge in order to comprehend spatial representations, such as the layout of a map of an area, or the layout of the area itself. In fact, individuals who are blind must rely on prior knowledge significantly more often than their counterparts do. However, limited access creates a situation in which memories of past experiences with spatial information fade over time before individuals with blindness are able to access incoming information. Therefore, comprehension of spatial information for individuals with blindness is a challenge in that they are not quickly able to rely on multiple past experiences stored in memory to recognize the importance of incoming spatial information in the present. In addition, the sequential encoding process from touch and movement while learning a new task can cause cognitive overload at a more rapid rate for individuals with visual impairments than would learning the same task via vision for individuals without VI.
Individuals with blindness must encode each step within a spatial performance task into memory before advancing onto the next step in the encoding process, because gathering information by touch and movement does not lend to rapid encoding of multidimensional objects.

Evaluating a New Conceptual Framework Through Theory and Practice

As discussed above, two bodies of literature need to be brought together in order to focus on graph accessibility and comprehension for SVI. I brought to bear the work of Paivio (2013) and Millar (1994) as theorists, along with literature centered on technologies and pedagogies for SVI in high school mathematics courses, to propose a mechanism by which SVI access and comprehend graphical information. In order to test the value of the conceptual framework, additional research is needed to provide a greater understanding of all of the components contained in the framework. I propose that assistive technology, instructional strategies and training are part of accessibility. I also propose comprehension to be a process that includes repeat occurrences of sequential encoding and integration. I use the beginning of this section to discuss gaps in the literature that research could fill, and the latter part of the section to suggest ideas for research to test the value of each component of the conceptual framework.

Based on Millar’s (1994) theory and a study conducted by Davison (2013), one would expect that SVI in high school mathematics courses use tactile graphics as the primary and preferred medium for accessing graphical information. However, no literature exists to provide insight into the most effective technologies for producing graphs SVI use when in high school mathematics courses. Evaluating the usability of
assistive technology will provide insight into the types of technologies SVI are likely to use when in high school mathematics courses.

Determining the worth of instructional strategies and teacher training within the conceptual framework will require further study. Barth’s (1983) report of the Tangible Graph Program and studies from Ferres et al. (2013) and Zebehazy and Wilton (2014a; 2014b; 2014c) provide evidence to suggest that individuals with visual impairments access and understand graphs by focusing on the referents (e.g., axes labels and values) before the function. This is in opposition to Pinker’s (1990) theory of graph comprehension for individuals with normal vision, which suggests that individuals with vision attend to the function before they address the referents. Dick and Kubiak (1997) and Quek and McNeill (2006) recommend that teachers provide hands-on instruction and clear language when teaching lessons on graphs. They suggest that it is reasonable that SVI in high school mathematics courses will benefit significantly more from pedagogy that involves guidance of the student’s hand through each element of a graphical representation, along with verbalization specific to that element on which the student has his or her hand. Research centered on instructional strategies by which SVI learn, as well as research centered on teacher training, could inform educators who have not had SVI in their courses as to the types of pedagogy SVI need and inform the training teachers receive to provide appropriate instruction to SVI.

Millar (1994) emphasized that individuals with blindness rely on prior knowledge significantly more than do those with normal vision. Yet they do not have the luxury of experiencing visual input to the full extent that their counterparts without visual impairments do. Millar suggested that the absence of vision causes SVI to adopt
cognitive mechanisms for understanding and representing space that differ from mechanisms individuals with vision use. Further research is needed to elucidate the cognitive mechanisms SVI use as they work with graphical information. In the subsections to come, I elaborate on possible avenues of research in the areas of theory, technology, and pedagogy as they relate to the conceptual framework. I suggest studies to test the value of sequential encoding and integration as part of comprehension, as well as assistive technology, instructional strategies, and training as part of accessibility.

**Theoretical Implications for the Conceptual Framework**

Individuals with normal vision learn through multiple modalities (Paivio, 2013) and experience challenges with graph comprehension (Carpenter & Shah, 1998; Pinker, 1990). However, the absence of vision greatly exacerbates the difficulties of accessing and comprehending graphical information for SVI. SVI often need individualized attention on a more frequent basis and for different reasons than their peers without visual impairments when in mathematics courses (McCallister & Kennedy, 2001). There is a small body of literature to support that SVI access and comprehend graphs in different manners than their peers. However, no theory or model has been developed as an attempt to predict how SVI learn graphical information.

According to Millar (1994), children with total blindness learn to represent and understand space through multiple rounds of sequential encoding before they begin to connect pieces of information into one another as the integration step in the conceptual framework. Carpenter and Shah (1998) used eye-tracking and think-aloud protocols as bases for developing a model of graph comprehension for students with vision. A think-aloud protocol, and finger-tracking rather than eye-tracking, could be used to develop an
understanding for how SVI learn graphical information in high school mathematics courses. Such an example could be an investigation of SVI in high school mathematics courses as they construct graphs and justify thought processes. The study could be conducted in a manner that involves the combination of think-aloud protocols and technology that tracks finger movements. An understanding of how SVI verbalize and use tools to produce tactile graphics could give insight into the sequential encoding strategies SVI use as they go about each step of a graphing task.

Millar (1994) emphasized that SVI rely on previous experiences to advance from encoding information sequentially to integrating multiple pieces of information to each other. One could develop a series of repeated tasks to determine whether a group of SVI learn how to construct tactile graphics and verbalize their actions more fluently through repetition over a given period of time. SVI could complete multiple series of tasks that involve the construction of tactile graphics and verbal protocols as discussed above. The decrease in time and errors for graph construction and verbalization could provide evidence that SVI have made the transition from encoding graphical information sequentially to understanding the graph as a whole for the integration step.

**Technological and Pedagogical Implications for Conceptual Framework**

There is a need for research in the realms of technology and pedagogy for SVI to successfully access and learn from graphs. This need is from the standpoint of teachers who have experienced SVI in mathematics courses, and from the standpoint of SVI and their teachers in a mainstream classroom setting. I propose examples of studies that one could conduct as means to test the value of the conceptual framework regarding assistive technology, instructional strategies, and training.
In order to assess the value of the framework as it relates to assistive technology, one potential study could gauge the quality of different types of assistive technologies SVI use for the purposes of graphing in high school mathematics courses. One could design the study such that students complete a classwork assignment with differing types of assistive technology while thinking aloud about their perceptions of the usability, efficiency, and limitations of the technology. The information gained from a usability study may benefit TVI by providing them with insight to share with educators as to the types of technology SVI are most likely to use when in high school mathematics courses.

In order to evaluate the importance of instructional strategies within the conceptual framework, I propose a replication of the Barth (1983) study on tactile graph interpretation. If such a replication results in findings similar to the original study, there may be value in implementing parts of the tangible graphing programs throughout institutions with SVI, and teachers in the K-12 system may be able to use what was learned from the replication study if they have SVI in their classes. If the findings at the current time do not align with the findings Barth reported, this situation may provide researchers with an avenue to explore how and why the findings were different, as well as various strategies that teachers may need to consider when providing graph instruction to SVI. In order to judge the significance of training for teachers as it relates to the conceptual framework, one could conduct a study that involves interviews with TVI and mathematics educators who provide instruction to SVI in high school mathematics courses. The perceptions of teachers who have provided instruction to SVI could give insight to researchers and teachers as to activities they may find beneficial if they happen to have SVI in their courses.
Conclusion

SVI are as capable of understanding spatial information as their peers with normal vision (Fisher & Hartman, 2005; Millar, 1994; Pritchard & Lamb, 2012; Quek & McNeill, 2006). The literature published on the learning behaviors of individuals with blindness suggests that they employ a very distinct set of cognitive mechanisms to understand spatial information in general, and graphs in particular. In this paper, I have proposed a conceptual framework as a first attempt to draw from existing theory to provide an explanation for how SVI access and comprehend graphs.

The conceptual framework could serve as a starting reference for researchers who intend to create or modify existing technologies and instructional strategies SVI rely on to access graphical information. It has the potential to be of great value for individuals engaged in research on technology and teaching strategies for SVI in high school mathematics courses, as well as TVI and mathematics educators who may experience SVI in a course they teach. The conceptual framework has the potential to guide further research in theory and in practice. This research has the potential to maximize opportunities for SVI to pursue advanced careers in science, technology, engineering, and mathematics.

References


CHAPTER 3. UNDERSTANDING TEACHER PERCEPTIONS OF ACCESS AND COMPREHENSION OF GRAPHICAL INFORMATION FOR SVI IN HIGH SCHOOL MATHEMATICS COURSES THROUGH A SURVEY WITH A MULTISTATE PERSPECTIVE

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Ashley Nashleanas

Abstract

Graphs are of great importance in many aspects of science, technology, engineering, and mathematics (STEM). However, because graphs are visual representations, they pose major issues for students with visual impairments (SVI) around accessibility and comprehension. Teachers of students with visual impairments (TVI) are responsible for ensuring that SVI gain access to graphs in a timely and effective manner, and a variety of tools exist to produce graphs for SVI. However, the literature surrounding visual impairment and graphs is sparse with respect to teacher perceptions of SVI needs for accessing and learning graphical information. A researcher-developed survey was used to understand TVI perceptions with regard to pedagogical practices and technological resources that benefit accessibility and comprehension of graphical information for SVI. A sample of 34 teachers with formal preparation in mathematics and teachers without formal preparation in mathematics were asked about their perceptions of instruction and technology SVI need to access and learn graphical information when in high school mathematics courses. Results indicated that TVI perceived SVI to exhibit different learning mechanisms than their peers with vision when using graphs, and time and multiple instructional strategies should be considered when teaching graphs to SVI.

Keywords: accessibility, comprehension, graphs, visual impairment
Understanding Teacher Perceptions of Access and Comprehension of Graphical Information for SVI in High School Mathematics Courses Through a Survey with a Multistate Perspective

Teachers of students with visual impairments (TVI) are responsible for ascertaining that students with visual impairments (SVI) receive sufficient access to graphical information in a timely manner. However, many TVI do not have a mathematics background and may not know how to aid SVI when learning concepts associated with graphical information. Mathematics educators do not receive training to teach graphical concepts to SVI. This is problematic for SVI in high school mathematics courses, as graphs are an integral part of high school mathematics curricula.

A limited corpus of literature exists to provide information on the types of pedagogies and technologies TVI believe will benefit SVI as they access and learn graphical information. The purpose of this study was to investigate, through a survey with a multi-state perspective, teachers’ perceptions of the technology and instruction SVI need in order to access and learn graphical information successfully. I first explore the literature that exists on the instructional practices from which SVI benefit for understanding spatial information, as well as the existing gaps in this literature. Next, I outline the methods used to develop the instrument and report the results. Finally, I discuss implications of the results, recommendations for future research, and limitations of the instrument.

Existing Literature and Gaps on Instruction for SVI

Millar (1994) emphasized that children with total blindness have the ability to access and comprehend spatial information, but the learning strategies they employ are vastly different from those of individuals with vision. Millar developed mental rotation
and reorganization tasks in which she tested children with blindness and blindfolded sighted children on their abilities to assemble one group of objects to match the shape of an object she had presented to the children at an earlier time. Children with total blindness and blindfolded sighted children were not significantly different in the average number of errors they made in any of the tasks she had asked them to complete. However, children with total blindness took significantly longer to complete the tasks than did blindfolded sighted children. Millar attributed the time lag in performance of children with total blindness to a difference in learning strategies between the two groups.

Millar (1994) noted that individuals with a small amount of vision and individuals with past visual experiences learn to recognize and organize objects through external reference frames. Individuals with limited vision, and those who have lost their vision, learn to understand and represent space from a holistic point of view. They access and integrate multiple objects in a simultaneous fashion, and they encode those pieces of information into visual memories. They repetitively connect incoming information to the images they have encoded into memory, and therefore, are able to gather and use information on a continual basis.

On the other hand, individuals whose blindness is congenital and total are not at liberty to access spatial information continuously or immediately as their sighted peers are able to do (Millar, 1994). Individuals who are blind use self-referencing strategies to understand and represent spatial information when they connect pieces of tactile information they experience in the present to information they have accessed long ago. Even when they are able to access the same type and amount of information as
individuals without visual impairments, individuals with total and congenital blindness require a longer period of time to comprehend accessible information.

Millar (1994) claimed that individuals with total and congenital blindness use touch to learn through systematic exploration. They use arm movements to find an object within reach, and then use hand movements to explore the object on a deeper level once they have found it. As the individual’s hands explore the item within reach, information about the item is encoded into memory in a piecewise manner. By integrating Millar’s theory with literature centered on mathematical and graphical instruction for SVI (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Pritchard & Lamb, 2012; Spindler, 2006; Zebehazy & Wilton, 2014), I developed a conceptual framework as a blueprint that explains how SVI access and comprehend graphs as spatial representations.

The conceptual framework was developed to explain how SVI access and learn graphical information in high school mathematics courses (see Figure 1). Literature on theory and instructional practices regarding SVI and spatial information served as the basis for developing the framework. Technology and instructional strategies are necessary for teachers to provide to SVI as they access graphical information, along with the necessary training they should acquire prior to teaching SVI. Millar’s (1994) theory of spatial representation in children with blindness predicts how SVI understand graphical information after their teachers have provided them with the technology and instructional strategies that allow them to access graphs.

**Assertions Regarding Graph Accessibility and Comprehension for SVI**

Based on literature that has discussed SVI and the conceptualization of mathematical and graphical information, I posed three assertions. First, SVI are as
capable of learning how to use graphical information as students with vision, but they are likely to require more time and attention from their instructors when learning how to use graphical information. Second, SVI will benefit from instruction that involves the use of tactile graphics, hands-on guidance, and verbalization. Finally, SVI are likely to organize and interpret graphical information by utilizing cognitive strategies that are different from those used by students with vision.

Figure 1. Conceptual Framework for Accessibility and Comprehension of Graphical Information for SVI in High School Mathematics Courses

SVI may need more time and attention from their instructors than students with vision when dealing with graphs. Secondary mathematics educators are likely not aware of the sequential strategies SVI use in order to learn visually oriented concepts (Pritchard
According to the American Foundation for the Blind (2018), SVI with vision loss only are likely to attend public K-12 institutions, while a combination of SVI with vision loss and those with additional disabilities are likely to attend schools specialized for instruction of SVI, known as residential schools. Over 80 percent of SVI are reported to attend classes in K-12 school systems throughout the country (Correa-Torres & Howell, 2004; National Federation of the Blind, 2016). However, the National Center for Education Statistics (US DOE NCES, 2016) reported that the incidence of SVI in a general education setting is a rarity, representing less than two percent of all K-12 students. Kahn and Lewis (2014) and Rule, Stefanich, Boody, and Peiffer (2011) reported that general educators do not receive specialized training to address the needs of SVI. SVI use a unique set of resources and learning strategies to develop an understanding of graphs and other visually oriented material (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014). For example, Zebehazy and Wilton (2014) conducted a survey to elucidate teacher experiences with instructional strategies for SVI in secondary mathematics courses. These researchers found that TVI perceive SVI to explore tactile graphics as disconnected pieces before understanding the graph as a whole, and that TVI observed a counterclockwise manner as the order in which SVI explore graphs. Meanwhile, their peers with vision are able to develop a holistic understanding with teaching strategies that take advantage of sight as the main sense of information absorption (Pinker, 1990).

Providing assistive technology in the form of tactile graphics to SVI is paramount as they learn to use graphical information. Graphs contain a combination of numbers,
letters, and shapes, and individuals read and interpret graphs by combining these components in a way they feel is necessary to understand the messages graphs convey (Pinker, 1990). SVI use assistive technology to access graphical information in the form of tactile graphics (American Printing House of the Blind, 2016), sonification tools (Davison, 2013), E-ink (Gorlewicz, Burgner, Withrow, & Webster III, 2014), and natural language assistive technology (NLAT) (Ferres, Lindgaard, Sumegi, & Tsuji, 2013).

However, Dick and Kubiak (1997) and Quek and McNeill (2006) stressed that assistive technology alone does not compensate for the unique learning strategies SVI exhibit as they grasp mathematical concepts that require a high level of graph reading and interpretation skills.

Supplying a combination of assistive technology with instructional strategies in the form of hands-on guidance and verbiage is necessary when teaching SVI to use graphical information. Quek and McNeill (2006) noted that SVI learn mathematical concepts through a combination of verbal communication and nonverbal exploration. Quek and McNeill stressed that mathematics instructors have the potential to help SVI understand how to verbalize graph-related concepts in their own minds and among peers when they use explicit descriptions of each component of a graph, for example, verbalizing the x-axis as an x-axis rather than referring to the x-axis as “that line there.” Instructors have the potential to enhance SVI understanding of the spatial layout of a graph when they intertwine the explicit descriptions with the act of guiding the student’s hand over each of the graph’s components. Individuals with blindness integrate information through multiple senses just as their sighted peers do (Millar, 1994). Therefore, teaching mathematics through a combination of explicit verbal communication
and guiding the student’s hands through a tactile representation accommodates the learning strategies SVI exhibit when comprehending concepts that involve graphical information.

SVI are likely to organize and interpret graphical information in a manner different from students with vision. There is little theoretical evidence to explain strategies SVI employ in order to comprehend graphical information. According to Pinker’s (1990) theory of graph comprehension, students with vision read a graph by attending to the title first, and they attend to the functional shape of the graph before attending to the referents. Barth (1983), Ferres et al. (2013), Quek and McNeill (2006), and Zebehazy and Wilton (2014) conducted studies whose findings suggest that individuals with blindness differ from individuals with vision in how they organize and comprehend graphical information. These researchers suggest that individuals with blindness first attend to the title, similar to individuals without visual impairments. However, the findings from these studies contradicted Pinker’s (1990) theory of graph comprehension, because individuals with blindness were likely to attend to the referents before they would attend to the functional shape of the graph. The “referents before function” scheme individuals with blindness are likely to use for organizing graphical information is in agreement with the step-by-step sequences Millar (1994) proposed children with total congenital blindness use to organize spatial information.

Difficulties Associated with Instructing SVI in High School Mathematics Courses

Secondary mathematics educators have received training appropriate for teaching lessons that involve graph reading and interpretation activities, but this is not the case for a majority of TVI (Pogrund & Wibbenmeyer, 2008). TVI are familiar with the learning
strategies that SVI use to understand and represent spatial information, as well as the types of resources they need for adequate access to spatial information (Suvak, 2004). However, DeMario, Lang, and Lian (1998) and Kapperman and Sticken (2003) reported that over 50 percent of TVI who participated in their studies shared that they were not trained properly in the Nemeth code (the code for braille mathematical notation) and do not have confidence to teach mathematics to their students.

Individuals responsible for teaching SVI should expect that their teaching strategies will benefit SVI only if they devote a significant amount of time and attention to their students, and accept that they need to adapt their instructional practices to accommodate to the mechanisms by which SVI access and learn spatial information (Dick & Kubiak, 1997; Millar, 1994; Quek & McNeill, 2006; Zebehazy & Wilton, 2014). Millar (1994) emphasized that individuals with low vision are able to use their existing vision to understand spatial information through external references, whereas individuals with total blindness do not have that luxury. Millar noted that a significant amount of time and attention are needed to develop the skills necessary for instructing individuals with total congenital blindness to perform tasks that are completed most easily through vision due to unique mechanisms by which individuals with visual impairments absorb information. When in a classroom setting, SVI are expected to keep pace with their classmates, and TVI feel they own the responsibility of holding their students to the same academic standard as their peers with normal vision (Correa-Torres & Howell, 2004). To my knowledge, Correa-Torres and Howell’s paper is one of the only examples in the literature to provide insight into the perceptions held by TVI regarding pedagogical and technological needs of SVI.
In developing this study, my goal was to initiate a discussion in the professional literature describing the current status of teaching graph accessibility and comprehension to secondary students with visual impairments. Given the unique nature of this type of teacher population, a web-based survey was employed for data collection.

Research Questions

Research questions one, two, and three provide the story line for the exploratory investigation of TVI perceptions as they pertain to the teaching and learning process involved with graph accessibility and comprehension for SVI. In the present study, graph comprehension is operationally defined as consisting of three parts: (a) instructional time and performance issues; (b) communication patterns, and (c) the sequence in which students address the six defining characteristics of a line graph. Research questions four and five involve teacher characteristics (demographics) that are viewed as experience variables that may relate to teachers’ perceptions.

1. Are there significant differences between the mean responses of TVI with formal education in mathematics and TVI with no formal education in mathematics as they judge the needs of SVI for time and performance on graphing tasks?

2. Are there significant differences between TVI with formal education in mathematics and TVI with no formal education in mathematics regarding the verbal and tactile cues they perceive SVI need?

3. Are there significant differences between TVI with formal education in mathematics and TVI with no formal education in mathematics as they judge the order with which SVI read elements of a tactile graphic?
4. Which characteristics (such as number of years teaching graphs to SVI, total number of students with visual impairments served, total number of students with total blindness served, and occupational setting) relate to the judgments of TVI regarding the pedagogical needs of SVI in high school mathematics courses?

5. What are the differences in responses between TVI who teach in a residential setting and TVI who teach in a public K-12 setting regarding technologies used by SVI when accessing and comprehending graphical information?

**Method**

**Participants**

**Survey sample.** Participants were identified with the assistance of a statewide mathematics consultant employed in a Midwest State. This consultant had access to professional network data identifying high school mathematics teachers who had formal preparation to serve students with visual impairments. The sample was restricted to high school teachers with experience teaching secondary school mathematics courses. Initial contact was made with 53 participants. These participants were employed in either a public school or private institutional setting (e.g., a residential setting). TVI were invited to participate in the study by responding to the web-based survey shown in the Appendices.

**Incomplete data.** Fourteen respondents did not complete the survey and five respondents did not meet the criteria because they were not high school mathematics teachers who also had formal training as a TVI. Thus, the data analyses were based on a sample of 34 teachers. This sample was the result of initially contacting participants in 18 states and Canada and reflected a return rate of 64%. Although the sample size is small
due to the unique positions TVI were filling professionally, the sample is representative given the “rule of thumb” criterion of a 60% response rate.

**Study sample.** The 34 TVI who completed the survey all had experience teaching SVI. However, TVI differed in their formal training in mathematics. This produced two subgroups of teachers based on their mathematics backgrounds: (a) a subgroup of 16 teachers with formal mathematics training and experience teaching students with visual impairments; and (b) a second subgroup of 18 teachers who had no formal training in mathematics but did have training in teaching SVI. The participants’ mean age was 50.6 (range from 28 to 70); participants’ race/ethnicity was primarily White (87.1%). The majority of the participants held master’s degrees and all but one taught in either an urbanized area or an urban cluster. Interestingly, nearly half noted that they had not taught normally sighted students in the last ten years. Participants’ mean years of teaching experience was 19.2 (range from 1 to 41) and mean years of teaching SVI was 14.5 (range from 2 to 39). With respect to employment setting, 23 were employed in residential settings and 11 were employed in traditional K-12 settings.

**Survey Instrument**

The survey consisted of six groups of questions, including (a) the types of graphs TVI had taught their students to use, (b) the amount of time and level of accuracy with which SVI complete graphing tasks relative to their peers without visual impairments, (c) teachers’ beliefs regarding the Verbal and Tactile Cues they give to SVI as they are providing instruction about graphs in a classroom setting, (d) teachers’ beliefs of how SVI read and organize graphical information, (e) types of technological resources to which teachers have exposed their students, and (f) the number of years teachers have
served SVI, services teachers provided to their students, and the settings in which teachers provided services to their students.

The second, third, and fourth blocks of questions represented three separate constructs. The first construct, Time and Performance, consisted of items that pertained to teachers' judgments of the time required for SVI to complete graphing tasks and SVI performance relative to their peers with vision. The second, Tactile and Verbal Cues, consisted of items that pertained to teachers' beliefs about the types of cues their students needed to understand graphical information. The third, Order of Graph Elements, consisted of items that asked about teachers' perceptions of the order in which SVI explore tactile graphics. Specific item wording and formats are presented in the appendices. Data were collected using Qualtrics (2018), a web-based data collection system.

**Procedure**

I emailed a Qualtrics link to the survey to the contacts provided through the mathematics consultant and carbon copied her on the same email. I informed the TVI that this consultant had given me their contact information, provided them with a general description of the study and the reason they were selected to participate, and thanked them for taking the time to complete the survey.

After I sent the invitation emails to all participants, I used the guidance of Dillman, Smyth, and Christian (2014) and sent follow-up reminders to those who had not responded to the survey. The reminder email thanked those who had taken the time to respond, and reminded those who had not responded that the survey was still open for
participation. The first follow-up email was sent three days after the original invitation, and subsequent follow-up emails were sent five days apart from one another.

**Data Analysis**

Research question one was addressed through the analysis of survey items 9-20. Research question two was addressed using data from items 21-23. These items assessed teachers’ perceptions of SVI performance relative to sighted students (9-20) and their communication patterns with SVI (21-23). Internal consistency reliability estimates were computed for the two sets of items separately. The Cronbach Alpha Internal reliability estimate for time and performance subscale items (9-20) was .80. The internal reliability estimate for the verbal and tactile cues items (21-23) was .44. These internal reliability data indicated that the two subscales should be treated as separate factors.

Research question three was addressed by items 24-29. These items tapped teachers’ beliefs about the order in which SVI organize their search pattern of graph elements as they decode a graph. Research question four sought to determine the relationship of teacher demographics to their perceptions and judgements of SVI. These demographics were captured by items 33-51. Research question five addressed the use of assistive technology when teaching SVI to access and comprehend graphical information. In this case, descriptive data were organized by the professional setting in which the teacher of the visually impaired was employed (residential or public school setting). Many of the survey items included an option for participants to indicate “don’t know.” When group means were calculated for particular items, the “don’t know” responses were excluded.
Results

Due to the small numbers involved, there were concerns about meeting some of the statistical assumptions underlying the statistical tests that were performed. Concerns involved two issues. The first was a conceptual issue. This involved the sample size and whether or not it was representative of the population. The response rate to the survey for the identified teachers was 64%, which exceeds the “rule of thumb” criteria for adequate response rate of 60% (Kerlinger, 1973).

The second issue was a statistical concern also related to a small sample size. This involved the question of normality of the distribution given that this is a basic assumption underlying the employment of parametric statistical analyses. The strategy suggested by a statistical consultant was to follow any statistical analysis involving the use of raw data and a parametric statistical analysis with a log transformation of the data that pertained to research question four to account for skewness and kurtosis resulting from outliers that were observed. The findings for the log transformed data are reported for results that differed from the raw data analysis. The following analyses are reported in the same sequential order as the research questions.

Research Question 1

The first research question addressed a difference between the perceptions of TVI with and without formal mathematics training who teach SVI in secondary mathematics courses. Consequently, teachers were separated into two groups in order to address this question. The first group ($n = 16$) included teachers with SVI licensure and no formal training in the teaching of secondary mathematics. The second group ($n = 15$) included
those teachers with SVI licensure and formal training in the teaching of secondary mathematics.

Teacher perceptions pertaining to the instructional needs of SVI regarding graph comprehension were operationally defined in terms of time and performance items (survey items 11-14 and items 17-20) and were treated as a single factor. Survey items used in this analysis and descriptive data for the sample can be reviewed in Appendix A.

A one-way analysis of variance (ANOVA) of group means was conducted in order to determine if significant differences existed in teachers’ perceptions of SVI needs due to differing professional training backgrounds. No statistically significant difference $F(1, 25) = .060, p > .05$, was observed. Thus, all responding teachers, regardless of professional background in mathematics, shared a common perspective regarding the speed and accuracy with which SVI complete tasks that require the use of graphs, relative to their peers with normal vision.

This was also the case for the level of performance observed by TVI when asked to compare SVI to average classroom performance. A one-way ANOVA of group means was conducted in order to identify group differences. There was no statistically significant group difference observed $F(1, 30) = .020, p > .05$. Regardless of differences in formal mathematics training, all teachers shared a common perspective when addressing the level of performance questions comparing SVI and their classmates with normal vision.

Because no statistically significant differences were observed regarding teacher perceptions based on differences in mathematics preparation, the two groups were combined ($N = 34$) and combined group performance was examined for selected
individual items in order to employ a more fine-grained analysis. An inspection of additional individual items does provide some insight. Survey items 9 and 10 reflect perceptions about the time frame (speed and accuracy) demonstrated by SVI when completing classroom tasks compared to normally sighted students. With regard to time (items 9 and 10), all teachers perceived that completing homework and exams containing graphical information required more time for SVI about 80% of the time. In terms of level of performance (items 15 and 16) relative to the class average, no consistent pattern of teachers’ perceptions was discernable. Items 13 and 14 were also inspected individually in order to determine teachers’ perception of the impact of the onset of the visual impairment on classroom performance. There was agreement that the onset of the visual impairment (congenital or later in childhood) impacts the level of accuracy with which SVI complete graphing assignments and exams (see Appendix A).

An interesting inference can be drawn from teachers’ perceptions of the frequency with which SVI perform at the level of the class average on homework and exams involving graphical information (items 15 and 16). Approximately one in three of the responding teachers “did not know” from previous experience how SVI would compare with a class average. This may simply reflect the fact that teachers in the current sample are working in residential settings or resource rooms in the public schools.

**Research Question 2**

When addressing the question of communication patterns while teaching graph comprehension (e.g., verbal and tactile cues), does formal training in mathematics make a difference in the level of verbal and nonverbal communication used during instruction? Again, no significant differences were observed in teachers’ perceptions as a result of
their professional training, \( F(1, 30) = .349, p > .05 \). Descriptive data are provided in Appendix B.

Results obtained while addressing research questions one and two lead to the following general conclusion. When all teachers in the sample have licensure for teaching SVI, whether or not they have formal mathematics training is not a determining factor in their perceptions of SVI.

**Research Question 3**

When addressing the specific issue of how teachers perceive the sequence SVI use to explore tactile graphics, the focus is on items 24-29. Descriptive data for these items are presented in Appendix C. Approximately two-thirds (68%) of responding teachers indicated that when encountering a graph, SVI accessed the title of the graph first in the sequencing of graph elements. For those teachers (68%) who identified the title as the initial element in the sequence, about half (43%) identified the graph function as the second element in the sequence attended to by SVI.

For the 31% of responding teachers who indicated something other than the graph title as being first in the processing sequence, three quarters indicated that students will likely focus on the graph function as the first element in the processing sequence. For the teachers who did not think SVI started with the graph title, there was no discernable pattern in their perception of how SVI sequenced the processing of the remaining graph elements.

**Research Question 4**

The nature of the relationship between teacher demographics and teacher perceptions was addressed with four simple linear regressions. Selected teacher
demographic variables (the total number of SVI taught; the number of students with congenital blindness taught; number of years teaching SVI; and teacher’s employment setting) were investigated for their impact on teacher perception of instructional time and performance issues.

Prior to looking at the relationship among demographics and teachers’ perceptions of SVI instruction time and performance levels, a consistent theme should be mentioned. As one might expect, a significant positive relationship $r = 0.59, p < .02$ was observed between the number of years teaching SVI and the number of students with total blindness served. This means that TVI with more experience teaching SVI are more likely to have served SVI with total blindness.

When addressing the relationships between teachers’ demographics and their perceptions of how often SVI complete tasks at least at the level of the class average, no significant relationships were observed for items 15 (completing classwork) and 16 (completing exams). This may have been due to the comparative standard “class average” in light of the large proportion of respondents who taught in residential schools, where the “class” consisted entirely of SVI. Further descriptive data can be found in Appendix D.

When addressing the question about the impact of onset of blindness on SVI and task accuracy (item 19), a significant positive relationship $r = .35, p < .05$, was observed. TVI who had taught SVI for longer periods of time were more likely to agree that prior visual experience was associated with performing graphing tasks more accurately. That is, TVI with more teaching experience perceived that students with previous vision perform graphing tasks more accurately than students born blind.
When addressing the question of whether students with low vision perform graphing tasks more accurately than students with total blindness (item 20), length of time teaching was again a factor, $r = .44$, $p < .01$. TVI who had taught for longer periods of time were more likely to agree that SVI with low vision were able to use graphs more accurately than SVI with total blindness.

**Research Question 5**

An awareness of the role of assistive technology would seem to be related to the occupational setting in which TVI teach SVI. This is not a teacher perception question, this is a teacher use question. As noted in the analysis of research question 4, participants’ demographic data fell into two distinctly different occupational settings; (a) residential schools and (b) public schools. Since student placement would not be a random factor, students in special school settings would seem to need a different array of assistive software and hardware in order to develop graph comprehension.

Of interest was the question of the general type of assistive technology (tactile or audio) teachers had experience with when teaching SVI. The following descriptive analysis provides some insight. Teacher responses to survey item 30 indicated that 10 of the 32 teachers had experience with tactile graphs only. The other 22 teachers reported using both tactile and audio formats. In terms of specific hardware and software graphing tools identified in item 31, the primary tools used by responding teachers fell into three categories: (a) Audio Graphing Calculators, (b) Tactile from Embossers, and (c) Tactile produced without Embossers.

When grouping the three categories of tools (items 32a and 32b) by (a) frequency of student use and (b) ease of use, in either a residential setting or public school setting, a
pattern emerged (see Table 1). In both residential and public school settings, the most frequently used assistive technology provided tactile stimulation from Embossers. This was followed by assistive technology providing stimulation without Embossers. Audio graphing calculators were the least frequently used form of assistive technology in both residential and public school settings.

When addressing the question about which form of assistive technology produces graphs that are easiest for SVI to use, a similar pattern was observed. Both residential and public school teachers agreed that graph producing assistive technologies that provided tactile stimulation were preferred. Additional descriptive data are located in Appendix E.

Table 1. Listing of Graphing Tools by Frequency and Student Ease of Use

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<thead>
<tr>
<th>Frequency of Tool Use</th>
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<th>Public School (n = 10)</th>
</tr>
</thead>
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<tr>
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<td>1</td>
</tr>
<tr>
<td>Tactile from Embossers</td>
<td>14</td>
<td>6</td>
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<tr>
<td>Tactile Produced without Embossers</td>
<td>8</td>
<td>2</td>
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<table>
<thead>
<tr>
<th>Ease of Student Use</th>
<th>Residential (n = 24)</th>
<th>Public School (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio Graphing Calculators</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Tactile From Embossers</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Tactile Produced without Embossers</td>
<td>12</td>
<td>5</td>
</tr>
</tbody>
</table>

**Discussion**

In the following subsections, I discuss the findings for research questions one through five. The remaining sections address the limitations of the study, as well as implications for practice and future research.
Differences in Responses between TVI with and Without Formal Mathematics Training

The Time and Performance and Verbal and Tactile Cues constructs were examined, and no statistically significant differences were found with respect to formal mathematics training. Descriptive analyses of the collective responses indicated that SVI require more time than their peers with vision when completing homework assignments and exams with graphical information. This finding parallels Millar’s (1994) theory of understanding spatial representations, along with studies conducted by Pritchard and Lamb (2012) and Spindler (2006) which showed that SVI required more time than their sighted counterparts as they complete activities in geometry and calculus assignments, respectively. This finding also aligns with what has been considered in the conceptual framework. SVI are likely to require more time on graphing tasks than their peers with vision, because the instructional strategies on which SVI rely are based on stepwise, systematic exploration as opposed to holistic learning.

When asked about the performance of SVI with respect to their peers with vision on tasks that involve graphical information, it was notable that a greater number of participants responded with “don’t know” than any other option. This result may have occurred because half of the participants had indicated that they had not taught mathematics to students with vision in the past ten years. Memories fade over time from one occurrence of a specific event to another occurrence of that event, according to Bahrick (2015). Therefore, a time gap of at least ten years without teaching students with normal vision may be why a majority of TVI responded that they did not know how SVI perform relative to students with normal vision on graphing tasks.
Also notable was the finding that participants indicated students with low vision would complete homework and exams with graphs more accurately than would their peers with total blindness, and students who have lost their vision over time would complete homework and exams with graphs more accurately than their peers blind from birth. These findings are noteworthy because they inform literature in fields surrounding visual impairment as it pertains to SVI understanding of spatial and graphical information. The body of literature around visual impairment and understanding of spatially oriented concepts shows that SVI are as capable of understanding spatial and mathematical concepts as their peers with vision, given the caveat that students with less visual experience may need more time and a different set of instructional approaches to be at a comparable level of understanding as students with more visual experiences (Dick & Kubiak, 1997; Millar, 1994; Quek & McNeill, 2006; Spindler, 2006; Zebehazy & Wilton, 2014).

With respect to pedagogical techniques, participants indicated that verbal communication alone would not suffice when teaching SVI to use graphs. The body of literature surrounding mathematics instruction for SVI, the conceptual framework, and the survey results suggest that tactile graphics, hands-on guidance, and announcing each component of a graph are key strategies for communicating graphs effectively and clearly to SVI. Though the survey results parallel the literature with regard to methods SVI should use to maximize accessibility and comprehension of graphical information for SVI, there are discrepancies between the survey results and the existing literature (e.g., Zebehazy & Wilton, 2014), regarding the ways in which TVI perceive SVI to attend to any given group of elements in a particular order. For example, a majority of TVI in the
present study stated that their students attend to the shape of the graph before they attend to the referents. This is contrary to Zebehazy and Wilton’s (2014) findings that TVI perceive SVI to explore tactile graphics in a counterclockwise manner. Although all respondents indicated that they had taught their students to use graphs, TVI perceptions of how SVI read graphs paralleled Pinker’s (1990) theory of graph comprehension specific to individuals with normal vision. Pinker’s theory states that, after reading the title, individuals focus attention on the graph’s shape before focusing attention on its other components.

**Impact of Teacher Characteristics on Responses**

The number students with visual impairments served, number of students with total blindness served, number of years teaching SVI, and primary occupational setting were considered as possible characteristics influencing TVI responses. It was expected that the experiences TVI have had (including types and numbers of students served, as well as types of educational contexts) are likely to impact their perceptions regarding SVI accessing and understanding graphs. Correa-Torres and Howell (2004) studied TVI who worked in both general education and residential settings and found that TVI felt responsible for ascertaining that their students were meeting expectations their peers with normal vision were expected to meet when in a regular classroom setting. When working in residential institutions settings for individuals with visual impairments, the focus tends to be on the individual, and improving his/her knowledge and skills, rather than on reaching expectations in reference to the general education peers as a group. The teaching strategies TVI use while serving students with low vision may resemble teaching strategies for students with normal vision, depending on the amount of vision. According
to Millar (1994), individuals with low vision are able to rely on the visual experiences they have such that they learn in a similar manner to students with normal vision, depending on the severity of the visual impairment. Millar stressed that the uniqueness of the job of instructing SVI is addressed only through lived experiences teaching and interacting with SVI.

The number of years serving SVI, number of students with total blindness served, number students with visual impairments served, and occupational setting were examined as possibly impacting TVI responses to four items: SVI performance with graphs on homework and exams (items 15 and 16) and teacher perceptions of visual experience and its role with regard to accuracy with which students complete graphing tasks (items 19 and 20). These items were chosen because the results obtained when examining TVI perceptions differed from the literature. For example, the “don’t know” responses teachers gave when asked about the performance of SVI relative to the class average, and the perceptions teachers expressed regarding the influence of prior visual experience on accuracy, contradicted findings from Millar (1994), Pritchard and Lamb (2012), and Spindler (2006) who suggested that students without visual experience are as capable as their peers with vision when dealing with spatially oriented concepts.

There was a significant positive relationship between the number of years teaching SVI and teacher perceptions of the role of prior visual experience on the accuracy with which SVI complete graphing tasks. TVI who served SVI for longer time spans were more likely to agree that SVI with prior visual experience perform graphing tasks more accurately than students whose blindness was from birth. TVI who reported greater numbers of years teaching SVI were more likely to agree that students with low
vision perform graphing tasks more accurately than students with total blindness.

**Teacher Perceptions Regarding Assistive Technology**

Teachers in residential and K-12 institutions did not differ in their perceptions regarding assistive technology. Participants collectively indicated that SVI tended to use tactile forms of assistive technology, either from embossers or as teacher-produced graphs with manipulatives, above all other available forms. In addition, a very small number of TVI perceived that their students easily or frequently used any other form of assistive technology such as Audio Graphing Calculators or natural language assistive technologies. This finding aligns with Millar’s (1994) theory, which stressed that SVI use touch and movement over any other form of sensory input to understand visually oriented concepts.

**Limitations of the Study**

This survey is the first of its type to be developed around teacher perceptions regarding graph accessibility and comprehension for SVI in high school mathematics courses, but it is not without limitations. Establishing the technical adequacy of the instrument (i.e., internal consistency and validity) was difficult. The survey had a small number of items pertaining to each construct, and some survey items were created to stand alone as opposed to being in a particular construct. Therefore, internal consistency was the only form of reliability that could be examined. Due to the nature and the organization of the items in the survey, content validity was the only reasonable form of validity used. Structural concerns such as ordering of items and the clarity of language within each item also needed to be considered. For example, a limitation lies in the construction of item 2 on the survey “Have you taught students with normal vision in the
last ten years?” with “yes” and “no” for selection, rather than requesting the number of such students taught in the last ten years.

A second limitation was the sample used in the study. A sample size of 34 participants limited the types of analyses that could be conducted and the interpretation of the results. Part of the sample size issue was the absence of secondary mathematics educators without a TVI credential. The present results apply only to the kinds of participants in the sample, all of whom had training as TVI. Mathematics teachers in the K-12 system, who may have had experience with SVI, but not TVI training, were not represented in this study.

Implications for Future Research

This section addresses implications for future research pertaining to level of visual impairment and quality of graphing work, the organization scheme by which SVI access components within graphs, resources for TVI to share with general educators, and new assistive technologies. The existing body of literature does not include studies that compare students’ performance on graphing tasks with respect to amount or onset of blindness. Further research is needed to ascertain student performance with graphing tasks as it relates to timing and level of visual experience. For example, a group of students with total congenital blindness could be compared with a group of students who have lost their vision over time using scores from past and current testing sessions that involve graphing. The results of this type of study could empirically test the impact of any vision on accuracy and determine whether teachers’ perceptions may lead to lower expectations of students who are congenitally blind.
While sufficient evidence exists to suggest what teachers should do to familiarize SVI with individual components of a graph, less information is available regarding the ways in which teachers show SVI how to read through an entire graph by assembling the individual components into a single entity. There is a need for further research to deepen understanding of how SVI read graphical information. One way to explore the order with which SVI access graph elements is to test whether SVI attend to graphical information differently than students with normal vision do. Future research could investigate the sequences SVI use to read tactile graphics. This information could provide teachers with recommendations on where to direct SVI from beginning to end as they discuss tactile graphics.

The TVI credential requires coursework centered on the appropriate procedures for providing assistive technology to SVI, the Nemeth code, strategies for teaching students with low vision, and strategies for teaching students with blindness. None of these facets are included as part of the curriculum for general educators (Suvak, 2004). Therefore, future research might consider the types of resources TVI have available to them and have found most useful in supporting SVI in high school mathematics courses as they are given opportunities to share these resources with high school mathematics teachers.

Although a greater number of TVI had responded that their students are likely to utilize assistive technology in the form of tactile graphics, electronic devices for educational use in classrooms are rising in popularity. Gorlewicz et al. (2014) emphasized that tools that include vibratory touchscreens as well as audio feedback could be potentially beneficial to SVI. These researchers suggest that touchscreens will reduce
the time teachers and aids devote to producing raised-line graphs and promote student independence. However, they emphasized that more testing and evaluation will need to be done to determine whether these tools will benefit SVI for accessing and learning graphical information. Therefore, SVI should continue to utilize raised-line graphs produced by embossers and tactile graphing aides and keep raised line graphs handy while testing new technologies when such opportunities present themselves.

Conclusion

Graphs pose challenges specific to SVI in ways that are not well understood by many in the educational arena. TVI have developed specialized skill sets to address these unique challenges. However, a literature gap exists with regard to the aspects of graph accessibility and comprehension that TVI perceive as necessities for SVI to access and understand them successfully. In this study, a researcher-developed survey was completed by teachers in 18 states as well as Canada. The results provide a deeper understanding of TVI perceptions around time and level of accuracy when completing assignments and exams with graphical information, the tactile and verbal cues that benefit SVI, and the order of elements to which SVI attend as they explore tactile graphics. Though a majority of the results were in agreement with literature around the behaviors of SVI with spatial and mathematical concepts, some of the perceptions TVI expressed either opposed or are potential additions to the existing body of research. Overall, the findings suggest future research for assessing instructional practices and resources specific to SVI learning needs with regard to graphing.
References


Appendix A. Research Question 1 Item Level Descriptive Statistics

Q9 How often do your students with visual impairments complete classwork that requires the use of graphs in a similar time frame relative to normally sighted students?

- 5 - between 80% and 100% of the time (5)
- 4 - between 60% and 79% of the time (4)
- 3 - between 40% and 59% of the time (3)
- 2 - between 20% and 39% of the time (2)
- 1 - less than 20% of the time (1)
- 0 - don't know

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Q10 How often do your students with visual impairments complete exams that require the use of graphs in a similar time frame relative to normally sighted students?

- 5 - between 80% and 100% of the time (5)
- 4 - between 60% and 79% of the time (4)
- 3 - between 40% and 59% of the time (3)
- 2 - between 20% and 39% of the time (2)
- 1 - less than 20% of the time (1)
- 0 - don't know

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Q11 I expect students with visual impairments to complete classwork that requires the use of graphs in a similar time frame relative to normally sighted students.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q12 I expect students with visual impairments to complete exams that require the use of graphs in a similar time frame relative to normally sighted students.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q13 Students who have had sight prior to becoming blind are likely to perform tasks that require the use of graphs more quickly than students who were blind from birth.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q14 Students who have low vision but are not completely blind are likely to perform tasks that require the use of graphs more quickly than students who are totally blind.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q15 How often do your students with visual impairments perform at least at the level of the class average when they complete classwork that requires the use of graphs?

- 5 - between 80% and 100% of the time (5)
- 4 - between 60% and 79% of the time (4)
- 3 - between 40% and 59% of the time (3)
- 2 - between 20% and 39% of the time (2)
- 1 - less than 20% of the time (1)
- 0 - don't know

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Q16 How often do your students with visual impairments perform at least at the level of the class average when completing exams that require the use of graphs?

- 5 - between 80% and 100% of the time (5)
- 4 - between 60% and 79% of the time (4)
- 3 - between 40% and 59% of the time (3)
- 2 - between 20% and 39% of the time (2)
- 1 - less than 20% of the time (1)
- 0 - don't know

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Q17 I expect students with visual impairments to perform at least at the level of the class average as they complete classwork that requires the use of graphs.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q18 I expect students with visual impairments to perform at least at the level of the class average as they complete exams that require the use of graphs.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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</table>
Q19 Students who have had sight prior to becoming blind are likely to perform tasks that require the use of graphs more accurately than students who were blind from birth.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q20 Students who have low vision but are not completely blind, are likely to perform tasks that require the use of graphs more accurately than students who are totally blind.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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**Composite Descriptive Statistics**

Percent of Time – Q9, Q10, Q15, Q16

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Expectations and Prior Visual Experience as Influence - Q11, Q12, Q13, Q14, Q17, Q18, Q19, Q20

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</table>
Appendix B. Research Question 2 Item Level Descriptive Statistics

Q21 When I am providing group instruction to a class and displaying graphs, the use of words such as "here", "there", "this" and "that", combined with gesturing, provide sufficient information for describing graph features to students with visual impairments.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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<td>0</td>
</tr>
<tr>
<td>% Missing</td>
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</table>

Q22 When they are given a tactile graphic for the first time, students with visual impairments are able to identify the features of the tactile graphic as I discuss it, without guidance from my hands.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

<table>
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<td>2.9</td>
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<td>5.9</td>
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</tbody>
</table>
Q23 With students with visual impairments, I am able to discuss graphical concepts without the use of a tactile graphic.

○ 5 - Strongly agree (4)
○ 4 - Agree (3)
○ 3 - Disagree (2)
○ 2 - Strongly disagree (1)
○ 1 - don't know

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**Composite Descriptive Statistics**  
Verbal/Tactile Composite – Q21, Q22, Q23

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</table>
Appendix C. Research Question 3 Item Level Descriptive Statistics

Q24 When given a tactile graphic, is it common for students with visual impairments to read the title before they discuss any other feature?

☐ Yes (1)
☐ No (2)

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Q25 Check which element you believe students with visual impairments focus on directly after they become aware of the title.

☐ Units on the y-axis (1)
☐ Scale of the y-axis (2)
☐ Units of the x-axis (3)
☐ Scale of the x-axis (4)
☐ Functional shape in the middle of the graph (5)

<table>
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<th>Value</th>
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<tbody>
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<td>% units on y-axis</td>
<td>23.8</td>
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<tr>
<td>% scale on y-axis</td>
<td>14.3</td>
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<tr>
<td>% units on x-axis</td>
<td>19.0</td>
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<td>% scale on x-axis</td>
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<tr>
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<tr>
<td># Missing</td>
<td>13</td>
</tr>
<tr>
<td>% Missing</td>
<td>38.24</td>
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</tbody>
</table>
Q26 Check which element you believe students with visual impairments attend to last as they explore tactile graphics.

- Units on the y-axis (1)
- Scale of the y-axis (2)
- Units of the x-axis (3)
- Scale of the x-axis (4)
- Functional shape in the middle of the graph (5)

<table>
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<tr>
<td>% Missing</td>
<td>38.24</td>
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</table>

Q27 When do you believe students with visual impairments are likely to access the title as they read tactile graphics?

- Near the beginning of the exploration process (1)
- Near the middle of the exploration process (2)
- Near the end of the exploration process (3)
- They don’t include it in their exploration process (4)

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<td>% near beginning</td>
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<tr>
<td>% near middle</td>
<td>20.0</td>
</tr>
<tr>
<td>% near end</td>
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<tr>
<td>% they don’t include it</td>
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Q28 Which element do you believe students with visual impairments are likely to attend to first as they explore tactile graphics?
- Units on the y-axis (1)
- Scale of the y-axis (2)
- Units of the x-axis (3)
- Scale of the x-axis (4)
- Functional shape in the middle of the graph (5)

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<td># Missing</td>
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<td>% Missing</td>
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Q29 Which feature do your students with visual impairments attend to last as they explore tactile graphics?
- Units of the y-axis (1)
- Scale of the y-axis (2)
- Units of the x-axis (3)
- Scale of the x-axis (4)
- Functional shape in the middle of the graph (5)

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Appendix D. Research Question 4 Mean Responses for Predictors and Outcome Items

Mean Responses for Predictor Variables
Q40 To the best of your memory, please indicate the number of years of overall experience you have served students with visual impairments.

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Q41 To the best of your memory, please indicate the number of students with blindness (unable to use printed sources) you have served in your career as an educator.

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Q42 To the best of your memory, please indicate the number of visually impaired students (able to read large print) you have served in your career as an educator.

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Frequencies and Percentages of TVI for Occupational Setting
Q45 Please identify your primary occupational setting.
- Residential institution (1)
- Public K-12 institution (2)
- Both (3)
- Neither (please specify) (4) ____________________

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<td># K12 (%)</td>
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<td># both (%)</td>
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<td># neither (%)</td>
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Mean Responses of Outcome Variables
Q15 How often do your students with visual impairments perform at least at the level of the class average when they complete classwork that requires the use of graphs?
- 5 - between 80% and 100% of the time (5)
- 4 - between 60% and 79% of the time (4)
- 3 - between 40% and 59% of the time (3)
- 2 - between 20% and 39% of the time (2)
- 1 - less than 20% of the time (1)
- 0 - don't know

<table>
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<td>32.4</td>
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</table>
Q16 How often do your students with visual impairments perform at least at the level of the class average when completing exams that require the use of graphs?

- 5 - between 80% and 100% of the time (5)
- 4 - between 60% and 79% of the time (4)
- 3 - between 40% and 59% of the time (3)
- 2 - between 20% and 39% of the time (2)
- 1 - less than 20% of the time (1)
- 0 - don't know

<table>
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<td>N</td>
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<td>32.4</td>
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</tr>
</tbody>
</table>

Q19 Students who have had sight prior to becoming blind are likely to perform tasks that require the use of graphs more accurately than students who were blind from birth.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Q20 Students who have low vision but are not completely blind, are likely to perform tasks that require the use of graphs more accurately than students who are totally blind.

- 5 - Strongly agree (4)
- 4 - Agree (3)
- 3 - Disagree (2)
- 2 - Strongly disagree (1)
- 1 - don't know

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Appendix E. Research Question 4 Frequences and Percentages of Assistive Technology

Q30 To which of the following technology formats have you introduced your students with visual impairments regarding graphical information?

- Tactile (1)
- Audio (2)
- Both tactile and audio (3)
- Neither tactile nor audio (4) SKIP TO END OF BLOCK

<table>
<thead>
<tr>
<th>Response</th>
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*Note. N = 34, # missing = 2*

Q31 To which of the following graphing tools have you introduced your students with visual impairments? Please check all that apply.

- Audio graphing calculators: Graph-It/Graph-It PC, Accessible Graphing Calculator, MathTrax, Orion TI-84 Plus Talking graphing calculator (1)
- Audio Sonification Software: Sonification sandbox, XSonify, Octave (2)
- Tactile from embossers: IntelliKeys, Phoenix embosser with Firebird software, Pictures In A Flash with swell paper, lock 8
- Swell-Form Graphics II (Heating) Machine with ThermoForm swell paper, Tiger Braille Embosser Series (Tiger Elite, Premier 100, Tiger Cub, Tiger Max, Braille and Ink: Emprint SpotDot, EmFuse High-Speed Embosser with Color Printing (3)
- Screen technology tactile and audio: Talking Tactile Pen, Talking Tactile Tablet 2, ViewPlus IVEO Touchpad 2.0 (IVEO Lite, IVEO Creator, IVEO Complete pro) (4)
- Tactile produced without embosser: Wikki Stix, Corkboard with tactile graph paper pins and elastic bands, Crafty graphics kits, Draftsman tactile drawing board, Graphic Aides for Mathematics with pins and rubber bands, tactile graphing paper with foam dots, brass snaps, or Wikki Stix nubs for points (5)
- None of the above (6) SKIP TO END OF BLOCK
### Q32. Please select one option for each question.

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Of the tools listed, which one is used most frequently by your students with visual impairments?

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CHAPTER 4. INVESTIGATING GRAPH ACCESSIBILITY AND COMPREHENSION OF STUDENTS WITH VISUAL IMPAIRMENTS THROUGH TEACHER PERCEPTIONS AND STUDENT EXPERIENCES

Publishing status: Not yet submitted for publication

Ashley Nashleanas

Abstract

Graphs are an integral part of mathematics, and students with visual impairments (SVI) benefit from technological and pedagogical practices that differ from teaching practices common to public K-12 education. In addition, technology and instruction that benefits each student varies from one student to another within the community of SVI. In this qualitative study, I report on the accounts of four teachers of students with visual impairments (TVI), two mathematics educators, and three SVI regarding the needs of SVI for access to and comprehension of graphical information in high school mathematics courses, as well as an observation of teachers supporting a single SVI in a high school mathematics course. I demonstrate that (a) mathematics teachers and TVI differ in their perceptions of supporting SVI to access and comprehend graphs, (b) TVI and mathematics educators are not the only resources for teaching SVI to use graphs, and (c) each SVI shares a unique account of the experiences with access to and comprehension of graphical information. Implications for future research are discussed.

Keywords: graph accessibility, graph comprehension, students with visual impairments
Investigating Graph Accessibility and Comprehension of Students with Visual Impairments Through Teacher Perceptions and Student Experiences

Visual representations are used in mathematics to relay large amounts of information quickly and effectively (Moon, Todd, Morton, & Ivey, 2012). Yet many times, students with visual impairments (SVI) do not have the means to access visual representations, and graphs are included in the many forms of visual representation mathematics has to offer (Millar, 1994; Pritchard & Lamb, 2012; Spindler, 2006). Teachers of students with visual impairments (TVI) work directly with SVI regarding needs specific to their visual impairment (Correa-Torres & Howell, 2004; Suvak, 2004). Yet, they may not have the expertise to assist SVI with graphing in mathematics at the high school level (DeMario, Lang, & Lian, 1998; Kapperman & Sticken, 2003). While mathematics educators may be well-versed in teaching the topic, teacher education programs have not prepared them for the unique needs and strategies SVI bring with them to the classroom with regard to mathematics in general and graphs in particular (Kahn & Lewis, 2014; Rule, Stefanich, Boody, & Peiffer, 2011). A limited literature base exists to provide information for how SVI access and learn about graphical information, as well as the role their teachers play in helping them to accomplish these tasks.

The purpose of this study is to understand teachers’ perceptions of support for SVI to access and comprehend graphs and SVI experiences surrounding graph accessibility and comprehension. Graph comprehension is a process that consists of various operations, for example, reading through a graph, interpretation of graphical information based on questions that might be asked about the graph, and construction of graphical information (Zebehazy & Wilton, 2014b). In this chapter, I first describe the existing literature and gaps regarding SVI and graphing. I then discuss my positionality
as a graduate student with total congenital blindness and the conceptual framework used to guide the study. Then, I describe the methodology, including the type of study, participants, and data analysis. Next, I report the results and discuss how the findings relate back to my research questions. Finally, I share the limitations of the study and implications for future research.

**Graph Accessibility and Comprehension for SVI**

Literature that addresses learning for individuals with visual impairments has focused mainly on cognitive processes employed by children with total and congenital blindness (Millar, 1994), (e.g., children born with a complete lack of vision). Millar (1994) emphasized that children who are totally and congenitally blind have the ability to access and comprehend spatial information, but the learning strategies they employ are vastly different from those of individuals with vision. In the following subsections, I discuss the literature that centers on the effect of visual experience on performing spatial tasks and give an overview of the techniques individuals with visual impairments use to learn graphical information.

**Onset of Visual Impairment and Performance of Spatial Tasks**

Although Millar (1994) declared that much of what is known about visual impairment centers around children with total and congenital blindness, studies from Dulin and Hatwell (2006) and Papadopoulos, Koustriava, and Kartasidou (2011) center on individuals with congenital blindness as well as individuals with previous visual experiences. Dulin and Hatwell (2006), along with Papadopoulos et al. (2011), contended that onset of visual impairment has an influence on the ability to understand spatial information. These researchers claimed that individuals whose vision loss occurs at some
point after birth are likely to understand their location within an environment and construct mental maps of a space they navigated with more accuracy than individuals with no visual experience. Papadopoulos et al. (2011) found that adolescents with late onset blindness were significantly more accurate than their counterparts with congenital blindness in keeping track of the relative positions of multiple objects at a time as they traveled through a large room with an odd geometric shape. Though Papadopoulos et al. (2011) did not provide an age of vision loss at which individuals were considered to experience early or late onset blindness, Dulin and Hatwell (2006) declared that individuals who lost their vision between four and eight years of age had early onset blindness, and individuals who lost their vision after the age of eight were considered to have late onset blindness. In the Dulin and Hatwell (2006) study, adults with congenital, early onset, and late onset blindness were asked to produce tactile drawings of the path of a moving object when given verbal directions of the object’s movement from one point to the next. Participants with late onset blindness drew routes that were significantly more accurate than their counterparts with either early onset or congenital blindness.

Although individuals with acquired visual impairments are suggested to perform spatial tasks significantly more accurately than individuals with congenital blindness (Dulin & Hatwell, 2006; Papadopoulos et al. 2011), Dulin and Hatwell (2006) also showed that expertise in the production of tactile graphics had an effect on the quality of performance with spatial tasks for individuals of different onsets. These researchers posited that participants with congenital blindness who had expertise in using tactile graphics produced more accurate representations of paths of moving objects than individuals who did not have as much experience with mapping but had prior visual
experiences. Hence, these researchers emphasized that the accuracy with which individuals produce maps can compensate for lack of visual experience, but the amount of time and cognitive effort individuals with congenital blindness must exert is significantly greater than for those with previous visual experiences.

Millar (1994) agreed with Dulin and Hatwell (2006) that individuals with total and congenital blindness eventually perform spatial tasks comparably to individuals with visual experiences, but these individuals should be provided with more opportunities and given more time to perform spatial tasks in order to be at the same level of accuracy as their peers with vision. As a demonstration of the difference between the approaches taken by individuals with and without vision to understand spatial concepts, Millar (1994) discussed the mechanisms by which individuals with and without vision travel routes. She reported that individuals with vision navigate routes using a holistic approach as they constantly integrate multiple sources of information at a time. Those who have vision are able to integrate and organize multiple pieces of information on an immediate and continual basis and are able to construct and use spatial representations quickly and consistently. On the other hand, individuals with blindness use touch and sound as vehicles for information uptake. Touch and sound cannot be used to integrate information with the speed and consistency that sight offers. Therefore, individuals who are blind organize spatial information in a self-referencing, sequential manner.

**SVI and Assistive Technology for Graphing**

Literature exists to suggest that individuals with visual impairments learn how to access and comprehend graphical information with specific types of assistive technology and in a sequential, step-by-step manner (Barth, 1983; Davison, 2013; Ferres, Lindgaard,
Tsuji, & Sumegi, 2013; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c). For example, Barth (1983), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c) suggest that individuals with visual impairments access graphs primarily through touch via assistive technology such as raised line drawing tools and braille embossers. However, Davison (2013) noted that individuals with visual impairments also access graphs via technology that provides information through a technique known as sonification. Sonification is a technique that employs sound as its medium of information output, and sonification technologies provide the user with information by a change in pitch, tempo, or volume to imply a change in variables such as time and speed. Meanwhile, Ferres et al. (2013) recommended that individuals with visual impairments access graphical information primarily through natural language assistive technologies (NLAT) that produce textual descriptions of a graph's components.

**Instructional Strategies**

Although assistive technology is the vehicle that individuals with visual impairments use to access graphical information through the senses of touch and sound, assistive technology alone does not suffice for individuals with visual impairments to access and comprehend graphical information to their full potential. Proper instruction is vital for these individuals to gain a deeper understanding of how to use graphs and the relevance graphs hold in a mathematical context (Barth, 1983; Ferres et al., 2013; Quek and McNeill, 2006; Zebehazy and Wilton, 2014a; 2014b; 2014c).

For example, Barth (1983) contended that students in middle school and high school learn about tactile graphics by focusing first on a line as its own entity, then on two intersecting lines, and finally on lines embedded within a grid system. Quek and
McNeill (2006) conducted a study in which a teacher at a residential school for the blind gave a lesson on understanding sine functions to a group of high school students. They emphasized the importance of providing a combination of hands-on guidance and verbal description of each component as saying "x-axis," "y-axis," and "the zero point" as opposed to "this," "that," "here," or "there."

Zebehazy and Wilton (2014a; 2014b) discussed the perceptions of TVI regarding instructional practices they provide with tactile graphics by students with blindness and print graphics by students with low vision, while Zebehazy and Wilton (2014c) discussed the perceptions of students with visual impairments regarding instruction they received. The teachers in Zebehazy and Wilton (2014a; 2014b) and the students in Zebehazy and Wilton (2014c) emphasized that tactile graphics users needed step-by-step, direct instruction to gain an understanding of what a graph is and how to use it. The teachers in Zebehazy and Wilton’s (2014b) study discussed the techniques they used when teaching their students to read tactile graphics, for example, exploring a tactile graphic in the counterclockwise direction and examining the vertical axis and its referents, the horizontal axis and its referents, and the functional shape. The sequential, step-by-step approach is vastly different from Pinker's (1990) "function before referents" approach to reading graphical information. According to Pinker (1990), individuals with normal vision are likely to gaze at components that appear visually different from the rest before they focus on symbols that appear similar and in close proximity to one another. Therefore, individuals with normal vision will gaze first at the title to get the gist of the graphical representation, and then focus on the functional part of the graph since each function takes on a unique shape depending on the graph type, for example, linear,
sinusoidal, or exponential. They then focus on the referents such as the axes, labels, and scales due to the proximity of the axes to one another and the similarity of the labels, as the labels are strings of text rather than images.

**Teacher Training**

The assistive technologies and instructional strategies individuals with visual impairments use differ from those used by individuals with normal vision (Dick & Kubiak, 1997; Millar, 1994; Quek & McNeill, 2006). The type and amount of training teachers receive stands as a point of concern regarding instruction for SVI in mathematics courses (DeMario, Lang, & Lian, 1998; Kapperman & Sticken, 2003). Mathematics teachers in the mainstream school system are not aware of what SVI need in terms of assistive technology and instructional strategies because they have had, at best, minimal exposure to SVI (Pritchard & Lamb, 2012; Spindler, 2006). The training that is provided in many general education programs does not address the needs of SVI (Kahn & Lewis, 2014; Rule et al., 2011). Over eighty percent of SVI are reported to be in the regular classroom as opposed to residential schools (Correa-Torres and Howell, 2004; National Federation for the Blind, 2016). However, the incidence of SVI in regular classroom settings still remains a rarity, less than two percent according to the National Center for Education Statistics (US DOE NCES, 2016). To my knowledge, there is no published research on the perceptions of TVI and general educators that serve the same student, or the experiences of that particular student, regarding the successes and challenges with access to and comprehension of graphical information, or how those perceptions and experiences are enacted in a classroom setting. As I explain further, my study addresses the perceptions of TVI and general educators as well as their students' experiences.
Positionality

My past and present experiences as a student with total congenital blindness caused me to be curious about how other SVI learn information in a classroom setting. I took advanced placement mathematics courses throughout high school at the times they were offered, and I enjoyed the material as well as the challenges associated with its mastery. My time as a student in high school mathematics courses was a valuable learning experience. I attended a school in which the maximum graduating class size was about fifty students. I was the only student with blindness in my class as well as throughout the entire school. My mathematics teachers knew that I happen to be blind and welcomed the experience of having me in their classes. Because of the small class sizes and familiarity with the people around me, I was not afraid to speak up and let the teacher know when a graphic was omitted from the textbook we were using. Likewise, the teacher was willing to meet with me on an individual basis either before or after class to discuss the omitted images. In order for the teacher to create tactile representations of the images, I brought raised line drawing tools and wax sticks known as Wikki Stix so the mathematics teacher could use the tools to create a tactile representation and describe each part of the image. I would make scratch notes of how I understood the image's parts and as a whole, as well as the teacher's description of the image and any references made during the class period when showing the image to the rest of the class. I also had a paraprofessional who used a braille embosser to produce the raised line drawings that were omitted from the textbook. Once she was able to produce the images with the embosser, I stored the images in a pocket folder and referred to them when appropriate.
After I completed high school, I received a Bachelor's degree in Chemistry and a Master of Science degree in Physical Chemistry. As an undergraduate and graduate student in a physical science, I was required to take many advanced mathematics courses (three semesters of calculus, one semester of linear algebra, and two semesters of differential equations). As an undergraduate and graduate student, I realized that not all individuals with visual impairments were as fortunate as I was in terms of the support their teachers provided them in high school. In spite of inadequate support, some were able to succeed and have become motivators for other individuals with blindness to succeed in mathematics and science disciplines. Unfortunately, others reported their experiences to be so poor that they lost whatever motivation they had to pursue any mathematics or science discipline. They instead decided to pursue degrees that did not require a strong understanding of graphs and other visual representations. My doctoral degree in Educational Psychology compelled me to investigate how other SVI access and understand graphs at the high school level.

**Conceptual Framework**

Pinker’s (1990) theory of graph comprehension applies to individuals with vision, but to my knowledge, there is no such theory of graph comprehension that applies to individuals with visual impairments. Therefore, I begin this section by discussing Pinker’s (1990) theory of graph comprehension for individuals with normal vision, and thereafter share Millar’s (1994) theoretical basis for understanding and representing spatial information as it pertains to individuals with blindness. Pinker (1990) proposed a theory of graph comprehension to account for the ways in which individuals with normal vision read and interpret graphical information. In order to inform Pinker’s (1990) theory
regarding graph exploration for individuals with normal vision, Carpenter and Shah (1998) used eye-tracking to investigate graph reading and comprehension skills of upper-level undergraduates. The findings from Carpenter and Shah (1998) affirmed Pinker’s (1990) theory, which suggests that individuals with normal vision understand graphs in a holistic manner as they scan the function before the referents. The undergraduates in their study gazed at and discussed the functional parts of the graphs they examined before they attended to the axis labels and scales. Pinker’s (1990) theory and Carpenter and Shah’s (1998) eye-tracking study provide information as to how individuals with normal vision read and interpret graphical information.

Millar (1994) stressed that individuals with visual impairments do not represent spatial information in the same manner as individuals with normal vision. In contrast to Pinker’s (1990) theory, Millar (1994) theorized that individuals with visual impairments understand a spatial representation in terms of its individual parts before they begin to connect each part into a whole representation. Millar (1994) focused on the strategies individuals with blindness use as they investigate tactile maps and travel routes. Millar mentioned that both graphs and maps are image systems that contain textual and graphical symbols, so individuals will use similar cognitive strategies to understand and represent graphs as they would to understand and represent maps. Millar (1994) stated that her theory of understanding and representing space is the most comprehensive account of how individuals with visual impairments understand and represent spatial information. Millar (1994) observed that individuals with visual impairments understand multiple types of spatial representations as maps and braille symbols. However, her theory of understanding space for individuals with visual impairments does not give a full
explanation of how individuals understand graphs as specific forms of spatial representation.

My conceptual framework (see Figure 1) is grounded in Millar’s (1994) theoretical standpoint regarding the mechanisms individuals with visual impairments employ to access and use spatial information, and literature regarding the assistive technologies and instructional strategies teachers use to facilitate these processes (Barth, 1983; Dick & Kubiak, 1997; Ferres et al., 2013; Pritchard & Lamb, 2012; Quek & McNeill, 2006; Spindler, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c).

![Conceptual Framework for Graph Accessibility and Comprehension for SVI](image)

Figure 1. Conceptual Framework for Graph Accessibility and Comprehension for SVI

The bottom half of the conceptual framework addresses the aspects that those serving SVI (TVI, paraprofessionals, and mathematics teachers) need to keep in mind as they present graphical information to SVI. Assistive technology, instructional strategies, and training are located inside of the circle labeled accessibility because assistive
technology, instructional strategies, and teacher training make graph accessibility possible for SVI. I elaborate more on the importance of assistive technology, instructional strategies, and training in the following sections.

SVI are able to gain sensory access to graphical information through assistive technology in many forms: tactile (American Printing House of the Blind, 2016; American Thermoform, 2016; ViewPlus Premium Braille Printers, 2016), sonification (Davison, 2013), and NLAT (Ferres et al. 2013). Each type of assistive technology carries its own set of advantages and disadvantages. Millar (1994), along with a large majority of researchers who study visual impairment and image exploration for individuals with visual impairments (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006), argued for the use of tactile graphics as the primary medium for access. Millar (1994) claimed that touch resembles vision more closely than any of the other senses, and individuals with total and congenital blindness have the ability to explore and manipulate objects with hand and arm movements that allow for encoding of information with more immediacy and redundancy than could be accessed by any of the other senses.

Millar (1994) contended that equipment used to produce tactile graphics is cumbersome and costly, whereas other forms of assistive technology are downloadable and free of charge. She considered that individuals with blindness will understand spatial information through aural cues only if they first understand spatial information through tactile cues. She explained that individuals with blindness learn to navigate space initially through locating objects within a space point by point, and this type of navigation relies on touch and movement. Touch and movement allow individuals with blindness to understand objects within reach, where sound alone does not. However, sound can
complement touch for individuals with blindness as they explore the space around them. Although sound complements touch, Millar (1994) emphasized that tactile maps enhance understanding of spatial representations for individuals with visual impairments. Likewise, with regard to graphical information, Davison (2013) emphasized that beginning graph users are likely to have an understanding of how the parts of a graph are related to one another if they explore it as a tactile representation before they are introduced to forms of assistive technology that produce graphs through sound.

In the conceptual framework, assistive technology is connected to instructional strategies through a straight line segment to indicate that providing assistive technology without the proper instruction for when and how to use it, will not suffice for SVI to access graphical information. I describe instructional strategies as verbal and tactile cues teachers provide their students given adequate assistive technology. For example, Dick and Kubiak (1997), Pritchard and Lamb (2012), Quek and McNeill (2006), Spindler (2006) and Zebehazy and Wilton (2014a; 2014b; 2014c) emphasized the usefulness of providing a combination of stepwise, hands-on instruction and clear verbiage to SVI once they are provided with the proper technological resources. Dick and Kubiak (1997), along with Quek and McNeill (2006) and Zebehazy and Wilton (2014a; 2014b; 2014c), emphasized that instructors should provide tactile graphics, hands-on guidance, verbal cues and encourage independence when teaching SVI how to use graphs. These researchers argued that teachers serving SVI should provide them with a tactile graphic so they are able to explore each part with their sense of touch. They then advised that instructors should provide SVI with hands-on guidance by placing the hand of the SVI over the instructor’s hand while going through each component of a graph. They also
contended that instructors should provide verbal cues by referring to components of a graph through language that describes the components by their mathematical terms. Last, they asserted that instructors should encourage SVI to be independent by motivating the student to explore the tactile graphic independently while watching the process and intervening when the student feels the need to be assisted.

The straight line located between assistive technology and instructional strategies connects to training to signify that SVI will benefit from assistive technology and instructional strategies their teachers provide, given the condition that teachers have sufficient training in the realms of instructional strategies and assistive technologies specific to SVI (Correa-Torres & Howell, 2004; Pogrund & Wibbenmeyer, 2008; Suvak, 2004). I describe teacher training as the skills teachers develop while earning their degrees as well as skills they attain through professional development. For TVI, professional development varies from one state to another and encompasses a variety of activities, some of which include taking courses designed to provide information on assistive technology and instructional strategies, as well as conferences specific to needs of individuals with visual impairments (Correa-Torres & Howell, 2004). For example, Louisiana Tech University offers professional development training through a Master of Arts in Counseling and Guidance/Rehabilitation program, which is designed to teach TVI how to instruct individuals with visual impairments to travel with the white cane and to use assistive technology (Professional Development and Research Institute on Blindness, 2018). Colorado offers a statewide conference for TVI within the state to learn about needs of children with blindness (Colorado Department of Education, 2017).
Millar (1994) posited that timing of access to spatial information is vital for individuals with visual impairments, because they are unable to access multiple sources of spatial information at one time through vision. I agree with Millar (1994) that the timing of access to graphical information is especially crucial for SVI given their limited experiences with spatial information relative to their sighted peers. According to Dick and Kubiak (1997) and Quek and McNeill (2006) the timing of access to graphical information for SVI plays an important role in their learning. Pritchard and Lamb (2012) described a student with total blindness who received access to geometry material weeks after it had been covered in class. In contrast, her peers had immediate access to the visual material and progressed with the teacher’s instructional timeline. To maximize the learning experiences of SVI with regard to graphical information, they to access such information in a similar time frame as their peers with normal (Dick & Kubiak, 1997; Pritchard & Lamb, 2012; Quek & McNeill, 2006).

Assistive technology, instructional strategies, and training make it possible for SVI to successfully access graphical information. Accessibility is connected to sequential encoding through a straight, single-headed arrow to signify that SVI can start the process of encoding graphical information into memory once they have been given the appropriate tools to access graphical information. I define sequential encoding as the first process that takes place in the minds of SVI once they have been able to access a graph. Millar (1994) described the process of sequential encoding for individuals with blindness as a step-by-step exposure to parts of a spatial representation that is new to them. Millar used the example of children with blindness and their exploration of tactile maps as a piecewise process as they feel their way from left to right across the top of the page and
work their way to the bottom of the page, and the relation of one part of a map to other parts of a map has not been established.

Millar (1994) posited that individuals with visual impairments need to encode information sequentially before they go through the process of integration (e.g., connecting one piece of a spatial representation to another piece in an integrative manner). Millar (1994) explained that the approaches individuals with visual impairments employ to process information differ from those with vision. Individuals with vision start to integrate information once they access it, something individuals with visual limitations are not able to do. Referring back to examples of how children with blindness cognitively process tactile maps, Millar explained that individuals with visual limitations integrate by understanding that each shape that makes up the map is connected to other shapes within the map, as well as the labels on the map that indicate what each shape within that map represents.

Sequential encoding and integration are connected to one another with a double-headed arrow to indicate that, while individuals with visual impairments start to process information sequentially before they can integrate pieces into a whole, the integration process informs future instances of sequential encoding. Integration is connected to comprehension through a double-headed arrow for the same reason that sequential encoding and integration are connected through a double-headed arrow. While integration takes place before comprehension, comprehension informs future instances of integration. For example, Millar (1994) emphasized that comprehending a spatial representation goes beyond knowing that the image as a whole contains multiple parts that are connected to one another. She explained that children with blindness begin to
comprehend a map by demonstrating that they are able to describe each shape by its label, where each shape is in relation to one another, and apply information on the map to a different task by travelling the route that the map portrays. She emphasized that a deeper level of comprehension would involve a situation in which individuals with visual limitations travel a route from one point to another using the cognitive map they have constructed, then describe the route they traveled through generating a verbal explanation or their own tactile maps to demonstrate how they got from one point to the next.

While two individuals may comprehend a spatial representation equally well, each individual may demonstrate their comprehension skills differently based on previous experiences that differed between the two individuals. More specifically, regarding graphical information, Zebehazy and Wilton (2014b) reported that TVI in their study shared that SVI learned to comprehend graphs by first starting with single parts and gradually integrating parts into a whole. Thus, I show comprehension as being connected back to sequential encoding through a single-headed arrow to indicate that comprehension of previous information informs sequential encoding of unfamiliar information, and that the process of sequential encoding starts anew for each spatial representation. To summarize, the bottom half of the conceptual framework encompasses the aspects teachers need to assist SVI with access to graphical information, and the top half represents the cognitive processes SVI are likely to use as they learn graphical information.

**Methodology**

I conducted a case study to explore the issues SVI encounter when accessing and understanding graphical information and how their teachers support them to learn
graphical information. Creswell described a case study as one that "involves the study of an issue explored through one or more cases" (2007, p. 73). Creswell (2007) discussed that a scholar may conduct a case study to gain a deeper understanding of an unusual or unique phenomenon that a very small number of people have experienced. Yin (2003) noted that a researcher engaged in a case study generally focuses on a phenomenon that takes place in a natural setting at the current time as opposed to historical events. The phenomenon for my study is graph accessibility and comprehension for SVI in secondary mathematics courses. The natural setting for my study is a classroom in which a mathematics teacher gives a lesson on graphical information and the class contains at least one SVI. According to the National Center for Education Statistics (2016), SVI between the ages of 4 and 21 comprise less than 2% of the United States population. Thus, it is a rarity for any high school mathematics teacher to experience SVI in their mathematics courses. Therefore, my study qualifies as a naturalistic study of a single case.

Geertz (1973) discussed the value of thick descriptions when he stated, “our data are really our own constructions of other people’s constructions of what they and their compatriots are up to” (p. 9). I applied Geertz’ (1973) explanation of thick descriptions to this study through my interpretation of the accounts of teachers regarding their perceptions of how they support SVI to access and comprehend graphs in high school mathematics courses, as well as their accounts of how their students access and comprehend graphical information. I carry my own biases of how SVI learn to access and understand graphical information, the challenges they encounter, teachers’ perceptions of how SVI learn and the challenges they face while accessing and understanding graphs,
and how teachers support SVI to access and understand graphs. However, I monitored my biases to bring myself “in to the lives of strangers” (Geertz, 1973, p. 16). In order to obtain the thick descriptions Geertz discussed, I addressed open-ended research questions with multiple data sources. The research questions for this study include:

1. What are teachers’ perceptions of how they support SVI to learn graphical information?
2. How do SVI in high school mathematics courses learn graphical information?
3. How do teachers support SVI in high school mathematics courses to learn graphical information?

**Participant Recruitment and Demographic Information**

In order to accomplish the goal of recruiting the individuals who participated in my study, I used purposeful sampling. Creswell (2007) described purposeful sampling as “the inquirer selects individuals and sites for study because they can purposefully inform an understanding of the research problem and central phenomenon in the study” (p. 86).

In the case of my study, the statewide mathematics consultant for vision services in a Midwestern state was familiar with all of the TVI and SVI throughout the state, as well as the mathematics instructors who serve these SVI. She informed all TVI throughout the state by email that I would conduct a study on graph accessibility and comprehension for SVI in secondary mathematics courses. She requested TVI to express to her whether they were interested in participating. I sent an email to all potential participants and carbon copied the consultant on the email. I informed each participant that she shared their contact information with me, gave a brief description of the study, and thanked them for expressing interest in participating in my study.
Table 1. Teacher Demographic Information

<table>
<thead>
<tr>
<th></th>
<th>Natty</th>
<th>Leah</th>
<th>Lois</th>
<th>Kenny</th>
<th>Bonnie</th>
<th>Lydia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>45</td>
<td>52</td>
<td>29</td>
<td>45</td>
<td>50</td>
<td>46</td>
</tr>
<tr>
<td><strong>District Size</strong></td>
<td>&lt; 2,500</td>
<td>&gt;50,000</td>
<td>&gt;50,000</td>
<td>&lt; 2,500</td>
<td>&lt; 2,500</td>
<td>Travels between districts</td>
</tr>
<tr>
<td># of years teaching overall</td>
<td>21</td>
<td>20</td>
<td>2</td>
<td>17</td>
<td>Na</td>
<td>10</td>
</tr>
<tr>
<td># of years teaching SVI</td>
<td>1</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td># of students total blindness</td>
<td>1</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td># of students with low vision</td>
<td>0</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Mathematics courses total blindness</td>
<td>Geometry</td>
<td>N/A</td>
<td>N/A</td>
<td>Algebra 1</td>
<td>Algebra 2, Geometry</td>
<td>N/A</td>
</tr>
<tr>
<td>Mathematics courses low vision</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Algebra 1 and 2, Geometry</td>
<td>N/A</td>
</tr>
<tr>
<td>Have taught SVI graphs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td># of years teaching SVI graphs</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>N/A</td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>

*Note. SVI = Student with Visual Impairment; “Mathematics courses total blindness” refers to courses in which teachers have taught one or more students with total blindness.*
Table 2. Student Demographic Information

<table>
<thead>
<tr>
<th></th>
<th>Guape</th>
<th>Bobbi</th>
<th>Kamden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>18</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Grade Level</td>
<td>Junior</td>
<td>Freshman</td>
<td>Sophomore</td>
</tr>
<tr>
<td>Current Mathematics Courses</td>
<td>Pre-Calculus</td>
<td>Algebra 1</td>
<td>Algebra 1B</td>
</tr>
<tr>
<td>Past Mathematics Courses</td>
<td>Geometry; Algebra 2</td>
<td>N/A</td>
<td>Algebra 1A</td>
</tr>
<tr>
<td>Onset of VI</td>
<td>Early</td>
<td>Late</td>
<td>Congenital</td>
</tr>
<tr>
<td>Current Technology</td>
<td>Both</td>
<td>Both</td>
<td>Tactile</td>
</tr>
<tr>
<td>Past Technology</td>
<td>Both</td>
<td>Both</td>
<td>Tactile</td>
</tr>
<tr>
<td>Preferred Technology</td>
<td>Tactile</td>
<td>Audio</td>
<td>Tactile</td>
</tr>
<tr>
<td>Braille</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Nemeth Code</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note. VI = Visual Impairment; Onset of VI refers to timing of visual impairment; Past Technology refers to the tools a student has used to access graphical information prior to the time of the interview sessions; Preferred Technology refers to technology SVI prefer to use for accessing graphical information. The Nemeth Code refers to the braille code used to represent mathematical notation.

Table 1 displays demographic information for each teacher who participated.

Three of the TVI in the participant pool did not teach mathematics courses, while one expressed that she team taught algebra and geometry courses. Although both mathematics teachers taught for about twenty years, they expressed that they had no experience with any SVI with the exception of those who participated in my study: Guape (taught by Natty) and Bobbi (taught by Kenny). In addition to the TVI and mathematics teachers participating in the study, two paraprofessionals participated–Jeannine and Merriam. To preserve anonymity, I assigned the names of all participants’ pseudonyms.

Table 2 displays demographic information for each student who participated. No student had the same onset, or timing, of visual impairment. Kamden was the only student who used solely a tactile form of assistive technology. Bobbi and Guape reported using both audio and tactile forms of assistive technology.
Data Sources

I invited mathematics teachers, TVI and SVI to participate in a 45-minute semi-structured interview on graph accessibility and comprehension for SVI. For a semi-structured interview, a researcher creates an interview guide with some assumptions of how participants may behave either verbally or nonverbally based on the literature in conjunction with personal experiences (Merriam, 2002). According to Merriam (2002), a researcher who conducts a semi-structured interview may deviate from the questions on the interview protocol if participants respond in ways that do not align with experiences or literature. I conducted semi-structured interviews with nine participants: four TVI, two high school mathematics teachers, and three SVI. I created the interview protocols to include questions that served as starting points for participants to respond about their perceptions and experiences with graph accessibility and comprehension for SVI in high school mathematics courses. I asked each SVI about resources and techniques to learn graphical information as well as the issues they encountered with learning graphical information. During the interview, I asked follow-up questions on challenges, instructional approaches, and resources participants discussed. One of the SVI (Guape) had a paraprofessional (Jeannine) who also served as a translator. Jeannine provided her insight when Guape was interviewed. Of the participants who responded, I worked with the consultant to find three of those individuals who fit into the same triad. A triad consisted of one TVI that serves SVI, one high school mathematics teacher who currently serves the same SVI, and the SVI. The identified triad included Kenny, the mathematics teacher, Merriam, the TVI, and Bobbi, the student.
I observed the triad during a 45-minute mathematics lesson on graphs. Kenny, the mathematics teacher, taught for the first twenty minutes, while Bobbi worked with Merriam on homework for the remainder of the time. During the classroom observation of the lesson, I recorded field notes of everything Kenny verbalized when teaching the lesson. I used the conceptual framework to guide me in the process of deciding on which points I focused my attention. I centered my attention on the amount and type of verbiage Kenny used to communicate graphical information, as well as the manner in which SVI Bobbi responded to Kenny’s teaching method. While I took notes of what I heard, Jackie (my technical assistant) recorded field notes of Kenny’s gestures and any visuals he displayed as well as Bobbi’s body language throughout the class period. After Kenny ended the lesson, Jackie and I moved with Bobbi and Merriam to another room in the building, where we observed a session in which they worked through three problems of the homework assignment. Jackie took notes on Merriam’s prompts and Bobbi’s responses while I listened. After the observation ended, Kenny provided me with the responses Bobbi gave to the exercises he assigned that day, and Jackie provided me with electronic access to Bobbi’s responses for the day’s exercises.

I conducted a follow-up interview with Kenny about the materials he used to present graphical information during the class period and his approaches for making those materials accessible to Bobbi. I also conducted a follow-up interview with Bobbi to understand her experiences regarding access to and comprehension of graphical information. I asked Bobbi how Kenny approached the issue of making the lesson plans and other instructor-related materials possible to access with the technology she uses. I triangulated the data from the interviews with the observation.
Data Analysis

I audio recorded each interview session and uploaded each recording to a password-protected system through the institution where I attend graduate school. I utilized a service recommended by a faculty member at the university to transcribe each recording once it was uploaded and shared with the employees of the service. After receiving the transcripts, I listened to each recording and read through each transcript to ascertain that the transcripts were accurate and all participants were de-identified. I also corrected instances in the transcripts where I found mistakes.

I analyzed the data as it was being collected. I coded the data given the advice of Saldaña (2009) for coding specific to case studies. For first cycle coding, I used attribute coding for the demographic information and notes on the observation site. Saldaña (2009) described attribute coding as, "a coding grammar, a way of documenting descriptive ‘cover’ information about participants, the site, and other related components of the study" (p. 57). Regarding demographic information, I recorded age, district size, years of experience teaching SVI, and grade levels for SVI as a few examples. When coding observation data that included the mathematics teacher's verbiage and hand movements, I assigned a phrase and a definition corresponding to that phrase to describe the combination of words and hand gestures the teacher used to communicate material to the students. Also for first cycle coding, I used structural coding for the interviews and observation. Saldaña (2009) described structural coding as: "a content-based or conceptual phrase representing a topic of inquiry to a segment of data to both code and categorize the data corpus. Structural codes are generally foundation work for further detailed coding" (p. 66). I assigned a word or phrase to participants' responses and
provided a description of each phrase by using a definition that I created based on literature.

In the process of coding the data, I established inter-rater reliability with a colleague who had sufficient experience with qualitative data analysis. We established two rounds of inter-rater reliability, one after I coded about a third of the interview data, and another after I coded about half of the interview data. After I coded about one-third of the data, I provided my colleague with a transcript to code independently. To give her background information about my codes, I gave her the most current version of the code book at the time along with the de-identified transcript. After she coded the transcript, we discussed any disagreements we had and found common ground. The first round of inter-rater reliability was 88.9%, and the second round of inter-rater reliability was 91.9%. Table 3 is a sample of my code book, which includes examples of recurring codes, a definition associated with each code, and participants’ accounts as evidence to support the code I chose.

After I coded all of the data from the interviews and observation, I used the approach referred to by Saldaña (2009) as pattern coding. According to Saldaña (2009), "Pattern coding develops the ‘meta-code’- the category label that identifies similarly coded data. Pattern codes not only organize the corpus but attempt to attribute meaning to that organization" (p. 150). I grouped codes together based on codes that repeated themselves and codes that were similar to one another. These groupings included ways mathematics teachers and TVI perceived support for SVI to access and comprehend graphs, the experiences SVI shared regarding challenges with access and comprehension, and the technology and instruction that helped SVI overcome those challenges. For
example, the codes “accessibility of teacher-prepared materials as teacher concern,”
“time as teacher concern,” and “independence as teacher concern” led to the subtheme
“mathematics teachers’ and TVI perceptions of concerns and resolutions.” As another example, the theme “SVI experiences with accessing and comprehending graphical information” emerged from the codes “reading a tactile graphic,” “constructing a tactile graphic,” and “visual memory eases graph comprehension.”

Table 3. Examples of Recurring Codes Extracted from Code Book

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making access possible through assistive</td>
<td>The instructor's willingness to provide the student with the devices he/she needs to hear and/or feel what their peers with vision see with their eyes.</td>
<td>“He has a graphic board with a pencil. So the teacher or I would tactile it on there and graph that way or I would do it and Wikki Stix” (Guape, interview translated via Jeannine, May 2017).</td>
</tr>
<tr>
<td>technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous instruction benefits</td>
<td>The instructor comments on connecting use of a tactile graphic with verbiage.</td>
<td>“A lot of what I have done with him is very hands on. It’s the using hand under hand if that’s what we need to do, you know, to help him feel where, what I’m talking about when we go through the graph, you know, talking about the axis and then how when at this point is where this number and this, this x axis number and this Y axis number meet” (Lois, interview, September 2017).</td>
</tr>
<tr>
<td>Reading a tactile graphic</td>
<td>SVI describes the method used to read a tactile graphic.</td>
<td>“I’d look at the title of the graph first and what the graph is going to be about, then I skip down to the side to look at, the numbering on there. And then I start, look at the bottom and then after that I look at the data in the graph” (Kamden, interview, October 2017).</td>
</tr>
</tbody>
</table>
Table 3. (continued)

| Constructing a tactile graphic | The instructor describes the process for teaching SVI how to create tactile graphics. | “We’re going to start on the right and you know, and showing the top, making her aware of the entire piece of either the paper or the tactile graphs or whatever we’re using and where we can put all the different parts, you know, where she would start at zero, if we’re going to a x-y axis, it would be, we would have, I would have her find the center and so have her find the center and we would put in the x and the y axis up to the, straight up from the center, to the top, straight down from the center to the bottom, straight to the right, straight to the left and we would then figure out how, what me need to measure, you know” (Lois, interview, September 2017). |
| Paraprofessional as an asset | The instructor or SVI comments on benefits derived from working with a paraprofessional. | “Merriam's right there with me, she said if we ever have a problem, which we haven’t at all yet, she said she can talk to him and just say I was right there and yes, it was 4 ½” (Bobbi, interview, November 2017). |

**Results**

In the following section, I report the perceptions of TVI and mathematics teachers as they support SVI for accessing and comprehending graphical information, as well as the experiences of each SVI during these activities for accessing and comprehending graphical information. I also report the findings related to the approach teachers take to support SVI needs for accessibility and comprehension of graphical information. The results reported here revolve around the three themes: Teacher Perceptions of Support for SVI to Access and Comprehend Graphical Information, SVI Experiences with Accessing...
and Comprehending Graphical Information, and Teacher Support for Students to Access
and Comprehend Graphical Information.

**Teacher Perceptions of Support for SVI to Learn Graphical Information**

I discuss the theme teacher perceptions of support for SVI to learn graphical
information in terms of the subthemes that emerged from the data: mathematics teachers’
and TVI perceptions of concerns and resolutions, and teachers’ perceptions regarding
paraprofessionals and mathematics consultants as beneficial resources for teacher
training.

**Mathematics Teachers’ and TVI Perceptions of Concerns and Resolutions**

TVI and mathematics educators differed in their concerns regarding graphical
information for SVI in mathematics courses, as well as how those concerns were
resolved. Mathematics teachers’ concerns centered on the amount of time SVI take to
complete graphing tasks, as well as access to material in textbooks and the lessons they
prepared. Natty (Guape’s mathematics teacher) expressed her concerns with his access to
textbooks and teacher-prepared material when she stated,

> I was very concerned about geometry. My biggest concern was having the
materials provided for him to be able to read and go back and reference what we
had talked about and obviously getting the textbook in braille was vital for him
and he would go back and could use all the textbook information, and things that I
would project upon the screen that maybe we didn't have a hard copy of that he
could read. (Natty, interview, June 2017)

Unlike Natty, who was concerned about Guape’s access to the material, Kenny’s
concern was on the amount of time it took Bobbi to do graphing exercises. Kenny
expressed that Bobbi was a gifted student, but needed to take more time with graphing
tasks. “She does very well and that if there is graphing that she has to do, it is pretty time consuming for her with the program that she had currently” (Kenny, interview, October 2017). Kenny shared that graphing took more time for Bobbi because of her attention to detail. Before having Bobbi in his class, Kenny had no experience with SVI and was not aware of what Bobbi and other SVI did to access and understand graphical information, or the specifics of why graphing was a lengthier process for SVI than it was for students with normal vision.

Both teachers expressed that their concerns were reduced when they started to recognize that their SVI were willing and able to use approaches that helped them to access and understand graphical information. Natty and Kenny articulated that their students were very intelligent and would not experience additional difficulties with learning the material despite the lack of vision. Natty proclaimed, "I was blown away by what he can do and what he can remember is incredible. He is very gifted mathematically" (Natty, interview, June 2017). She elaborated on some of the approaches he used to access and comprehend graphical material in her class.

He had a tactile board and we would use the wax to put on there for the axis and he could plot points that way. He would create it with the wax on the paper and he had braille paper with graphs on it, the axis's on there that he would plot. Even when we would talk about coordinates in class his memory is amazing. (Natty, interview, June 2017)

Natty attributed Guape’s strong graph comprehension skills to his ability to construct graphs with assistive technology and draw from memory in general.
While Natty claimed that Guape’s success with graphing was due to his ability to use assistive technology and rely on memory, Kenny stated that Bobbi’s giftedness in mathematics was a result of her prior visual experience. Kenny mentioned that he could resolve the concerns he had about the time involved for Bobbi to do graphing assignments by reducing the number of exercises she did in comparison to the rest of the class. Kenny articulated that, even though Bobbi’s assignments were reduced with regard to the other students, Bobbi was getting adequate practice with the material and still continued to be successful in his class. Kenny attributed Bobbi’s giftedness to her prior visual experiences, as he replied, “A lot of it’s her prior knowledge from when she could see. She can visualize things because at one point in time she could see. So, she knows what it should look like” (Kenny, interview, November 2017).

While mathematics teachers expressed general concerns and issues about whether material was produced on time and the amount of time their students needed to complete graphing tasks relative to their peers with normal vision, TVI had more specific concerns about technology and how their students learned the material. For example, Leah (TVI) elaborated on the formatting issues she and her students came upon when using tactile graphics.

The problem with graphs that we have discovered over the years is there's often too much information that's tried to cram into a graph and then when you're trying to discern all that information tactiley it gets garbled. They often are not clearly marked so that you can feel the difference between the lines. They use the same tufting to draw the diagonal line that shows the data, same materials are used to create the lines on the graph itself. So it gets blurred. (Leah, Interview, June 2017)
Leah explained further that the formatting issues her students experienced with tactile graphics created issues for them while learning the material when she responded,

With the line graph it's crossing over other lines and it's just harder to read. Even if we use puff paint or even if they use Wikki Stix, it still is harder to accurately read if it's a year 1980, you know the years are going up there five years but by line or something it's harder and then to follow the line down to see on the $y$ axis or the $x$ axis and it's harder, it's just harder. I don't know why it is but it just was for my students. (Leah, interview, June 2017)

Bonnie (TVI) expressed concerns about tactile graphics that differed from Leah’s concerns about formatting. Bonnie voiced that TVI and paraprofessionals provided SVI with too much assistance as they were learning to construct graphs. She expressed that the assistance the teachers provided had a negative impact on SVI independence to construct graphical information and their ability to understand concepts with graphical information. Bonnie articulated, “I don’t think they got the concepts as well and I don’t think they really made them independently” (Bonnie, interview, May 2017). Lois (TVI) agreed with Bonnie’s concern that too much assistance prohibits student independence and conceptual knowledge. Lois was concerned that SVI Kamden had difficulty in performing tasks with multiple steps and distinguishing positive integers from negative integers when she said he had trouble with “finding $x$ and then finding $y$ and then putting them in the right place on the graph. He struggled with the positive and the negative, where they go on the graph” (Lois, interview, September 2017). Lois’ concern with Kamden was that he was not understanding how to use graphs because his previous paraprofessionals performed tasks for him that he was now expected to complete
independently. Her idea of resolving the issue was to push Kamden to become more independent through asking him questions about his work if it was incorrect, reinforcing that his progress was good when he provided correct responses to homework problems, and letting him know she was confident that he would be successful in mathematics. The accounts TVI provided about formatting issues with tactile graphics and an overabundance of assistance from instructors imply two things. It is necessary for teachers to find ways of improving the quality of graphs produced by assistive technology and making sure their SVI can identify each part. Rather than doing the work for the student, it would benefit all teachers serving SVI to maintain awareness of the amount of assistance their students need as they learn about graphical information and adapt their teaching style based on the student’s performance at the time.

Teachers’ Perceptions Regarding Paraprofessionals and Mathematics Consultants as Beneficial Resources for Teacher Training

Mathematics teachers and TVI articulated that the skills they acquired were due to certain aspects of training they received from individuals who served the SVI they work with now. Mathematics teachers and TVI agreed that paraprofessionals served as valuable resources to help them learn how to provide their students with access to teacher-prepared material. TVI also shared that their interaction with the mathematics consultant for SVI, as well as their interaction with their students’ paraprofessionals, were essential educational tools for them to learn from as they worked with SVI on graphing tasks.

Natty (Guape’s mathematics teacher) expressed that it would have been difficult to learn how to teach Guape without the resourceful instruction Jeannine (Guape’s paraprofessional) provided while Guape was in her class, as she said, “Had we had not
had somebody like that I think it would have been a much more difficult situation” (Natty, interview, June 2017). Natty elaborated on the ways in which Jeannine was a resource to her in terms of being an advocate for Guape to receive materials on time and proper instruction with the response,

She has worked with him for a long time so she was a huge advocate for him and knew what needed to be done obviously. He's been in our school system for a long time so we knew that he would be coming, entering into our classes and she knew what resources were available, what we needed to do for books and so all of that was done the summer before he entered the high school and we had the materials ready for him and prepared. (Natty, interview, June 2017)

Natty emphasized that her interaction with Jeannine lessened the time and effort she otherwise would have spent searching for approaches to help Guape with access to material as she shared,

I would have to have researched resources myself and found needed information. Obviously I know that there are things out there as far as having it written in braille for him. It just would have been more placed I think on my shoulders to have to dig deeper for some of those things. (Natty, interview, June 2017)

Natty’s comments suggested that paraprofessionals such as Jeannine are valuable resources for mathematics teachers to learn what SVI need for access to graphical information.

While Natty was focused on Jeannine’s ability to help her with aspects that center on assistive technology, Kenny (Bobbi’s mathematics teacher) focused on the advice Bobbi’s paraprofessional, Merriam, provided him as he presents graphs in the classroom.
Kenny mentioned that Merriam reinforced that he needed to verbalize all that he puts on the board due to Bobbi's lack of vision and the approach she used to take notes. He stated,

I would say, just talking to the aide that works with her cause she’s been with her for quite a few years. She just told me that we just got to remember she’s writing what you say, not necessarily what you write on the board so, that was something where I figured I need to repeat myself so that she makes sure she gets everything written down. (Kenny, interview, October 2017)

While Natty was focused on Jeannine’s assistance in providing the material to Guape on time and Kenny was focused on Merriam’s advice to provide verbal cues for Bobbi when in class, TVI Lydia and Lois voiced that the abilities of their students’ paraprofessionals to construct tactile graphics was of value. Lydia and Lois asserted that while they learned about making tactile graphics, a paraprofessional could serve as an asset to constructing tactile graphics for SVI when TVI are not able to spend the time constructing tactile graphics for SVI. For example, since Lydia was not in the classroom with her student on a regular basis, she discussed the value of the paraprofessional, who was in class with the student and was willing and able to make the tactile graphs.

Lois was similar to Lydia in that she was not able to meet with Bobbi on a regular basis, which left Merriam to prepare graphs for Bobbi. Lois gave an account of how Merriam helped her to realize that it is the teacher’s responsibility, not Bobbi’s, to create tactile graphs that Bobbi needed for class. She explained,

When I first started, the way she accessed it was through her para educator reading and explaining the graphics to her or it’d be made a tactile for her. Not
her making it herself but someone making it for her. (Lois, interview, September 2017)

Lois expressed that, as she continued to interact with Merriam, she started to realize that Bobbi’s teachers made accessible versions of graphs that did not come in an accessible form ahead of time so that Bobbi could have immediate access as her peers did in class.

TVI asserted that the skills they acquired, as well as the skills the paraprofessionals developed, were a result of the training they received from the mathematics consultant for SVI. Lydia mentioned that the consultant provided her with the skills she needed to teach students to use the Audio Graphing Calculator (e.g., a tool that generates graphical information through changes in pitch) and work with tactile graphics. Lydia also shared that the consultant provided tips to refresh her memory on how to teach one of her students to use the Audio Graphing Calculator because she does not have to teach SVI how to use the Audio Graphing Calculator regularly.

She [the consultant] offers the most help probably of anybody that we have. She’s willing to come out and work with the students or work with us, cause we don’t use it. I had a student using the graphing calculator four years ago but I didn’t use it in between. I always have to have a refresher. (Lydia, interview, September 2017)

In addition to the consultant’s tips with the Audio Graphing Calculator, Lydia voiced that the consultant provided professional development opportunities that allowed Lydia to teach her students to use tactile graphics with unique approaches.

Our math consultant has provided several of them that I’ve been to, they’re mostly around adapting things to make tactile graphics and other ways to
demonstrate math concepts. One time she brought in cookie sheets that had tapes and magnets on all of them. (Lydia, interview, September 2017)

Lois agreed with Lydia that the consultant was an asset for training TVI and paraprofessionals to teach their students to use tactile graphics. She expressed that the training sessions the consultant led were of value as she learned along with other TVI and paraprofessionals about how to make tactile graphics and how to teach SVI to make their own tactile graphics. The various accounts TVI shared about the consultant and their students’ paraprofessionals suggests that teacher training for TVI can come in many forms, one of which is learning from teachers who have experience with the SVI they serve in mathematics courses throughout the state.

**SVI Experiences with Accessing and Comprehending Graphical Information**

I discuss the theme SVI Experiences with Accessing and Comprehending Graphical Information in terms of the subthemes that emerged from the data: SVI experiences regarding challenges with assistive technology, SVI experiences regarding access to graphs in textbooks, SVI experiences regarding graph exploration and construction, and SVI experiences with graph comprehension.

**SVI experiences regarding challenges with assistive technology.** Students Guape, Kamden, and Bobbi discussed the challenges they encountered with assistive technology. Each student was unique in the specific types of assistive technology they used and the challenges they encountered. Guape lost all of his vision by the age of five. Braille has been and continues to be the only medium by which Guape is able to read, and he is fluent in the Nemeth code. Guape and Jeannine (his paraprofessional and translator) discussed that Guape has not experienced issues with tactile graphics but has
experienced several issues with the Audio Graphing Calculator. Guape explained his challenges with assistive technology that produces graphs in audio form. “Well technology sometimes is that I don't exactly know what it is… certain ways to get the information that the teacher or I want to get to. I usually ask the teacher and we struggle through it” (Guape, interview, May 2017). Guape shared that he was uncomfortable with technology that produces graphs through sound due to his lack of familiarity with the technology.

Jeannine added to Guape’s discussion about challenges with assistive technology that produces audio graphs when she explained,

In just talking with the science teacher today they struggle with TI84 [a form of the Audio Graphing Calculator] and I think a lot of it is because he's not used it enough and become familiar enough with it and so then the teacher has to take time out of his class in order to help him with it and so at this point they kind of put that at the wayside. Guape doesn't have the knowledge of that or maybe the short keys to run with that a little bit quicker and so he struggles to find those short keys or has to look at a cheat sheet and then from the cheat sheet to the computer. (Guape, interview with translation via Jeannine, May 2017)

Jeannine mentioned that the teacher who knew the most about the TI84 did not have the time to teach Guape how to use it, which in turn, made Guape feel uncomfortable in learning the TI84. As a result, he defaulted back to using tactile graphics.

Like Guape, Kamden was born with a visual impairment severe enough that he could not use large print. Kamden reported that he read and constructed tactile graphics as well. He used tactile graphics in multiple forms, one of which was a large graphing
board known as the Graphic Aide. The Graphic Aide is a large rubber board with a raised grid and comes with pushpins for the points and rubber bands to represent connections between pins. Kamden mentioned that the Graphic Aide was useful and he was able to read and construct graphs successfully. However, its size was enough of an issue that he was not able to bring it with him to work on graphs unless he worked in the room where the Graphic Aide was stored.

Bobbi, who had normal vision until the age of ten, shared the same complaint that Kamden did about portability as an issue with the Graphic Aide. She elaborated on the challenges with using the Graphic Aide as it pertains to the time it takes her to complete homework assignments, as well as the difficulty Kenny has in evaluating her responses as she uses it. Regarding the time it takes to use the Graphic Aide as she completes homework assignments, Bobbi shared,

It just takes up so much extra time that sometimes I almost feel like it’s more of a burden because I could be getting other homework done and I’d already be done with my math assignment, but I have to sit here and do twenty graphs. Each time you have to take out all the pins, all the rubber bands and then you have to put them along. You have to feel for each individual marker, each individual line and just getting the pins exactly where you want them, since the pins are bigger.

(Bobbi, interview, November 2017)

Bobbi’s report of why it takes her more time to complete graphing assignments explains Kenny’s concern, discussed earlier, regarding the time required for Bobbi to complete homework assignments with graphing. Bobbi also discussed that it is a challenge for Kenny to evaluate the responses she gives on homework assignments when
she uses the Graphic Aide. For example, she explained that Kenny had difficulty
deciphering whether the location of a pin was set at the point \( x = 4 \), or whether the pin
was placed between the points \( x = 4 \) and \( x = 5 \). In order to resolve the issue, Bobbi
communicates the value at which the pin is placed by typing a side note within the
assignment where she intended to put the pin.

While Kamden and Guape expressed that they did not have issues with raised line
tactile graphics, Bobbi shared that she has issues with using them. Bobbi was used to
learning about graphs aurally through verbal descriptions rather than using tactile
graphics like those produced with the Graphic Aide. Bobbi has been using a program
known as Google Sheets to read and construct graphs and became exposed to tactile
graphics this fall. Bobbi expressed peer distraction as an issue she encountered with
tactile graphics. "Tactile graphics, I don’t use quite as much just because it’s so much
slower" (Bobbi, interview, October 2017). Also, Bobbi discussed peer distraction as an
issue with using tactile graphics.

And then even in classroom stuff, the kids would all want to feel my tactile graph
and they’d want to mess around with it even when I told them no, I’m working, it
would still be trying to play with the materials that I was using and so, it became a
distraction in class. (Bobbi, interview, October 2017)

Bobbi mentioned that her level of independence with accessing graphs was
limited when she used tactile graphics. “I almost felt a little less independent because I
was relying on someone else to help me figure out if I miss one and then on the computer
I can just do it all myself” (Bobbi, interview, October 2017). She was dependent on
someone else when using tactile graphics because:
Just having to feel for every bump and then placing it down and then having to find all those bumps again and then draw the line and then double check it and recheck it and then have my para check it to make sure I didn’t leave a dot out.

(Bobbi, Interview, October 2017)

Though Bobbi expressed challenges with tactile graphics, she intends to continue seeking approaches for using tactile graphics to compensate for her vision loss. The accounts Guape, Kamden, and Bobbi provided about the assistive technology they use for graphing suggest that the severity of an individual’s visual impairment, time spent on instruction, and the degree to which an individual uses assistive tools independently stand as reasons for why each SVI faces a unique set of challenges with assistive technology.

**SVI experiences regarding access to graphs in textbooks.** SVI discussed the variety of mistakes in braille textbooks as a challenge around accessing graphs. Kamden shared that many of his textbooks contained mistakes with spacing and incorrect placement of numbers within graphs. Bobbi experienced similar issues as Kamden regarding mistakes within the textbook. Some of the issues she expressed were homework exercises that were omitted and the placement of multiplication signs where equal signs would have been more appropriate.

Kamden and Bobbi discussed the value of their paraprofessionals in helping them to resolve issues that they came upon with their textbooks. Kamden said that he and his paraprofessional handled issues with the textbook. He said, "We make our own graph if it’s not doing a very good job at showing, she just copies it out of the book and kind of makes a replica of it" (Kamden, interview, October 2017). Unlike Kamden, who is fluent in the Nemeth code, Bobbi found it helpful for Merriam to read the textbook out loud so
she could catch the mistakes as she was following along in her textbook. The accounts
Bobbi and Kamden gave regarding their textbooks suggest that textbooks used by SVI in
mathematics courses can contain a variety of mistakes, and paraprofessionals are valuable
resources in working with students to find alternative approaches to handle mistakes they
find in their textbooks.

SVI experiences regarding graph exploration and construction. Graph exploration
and construction are the beginning operations of the larger process of comprehension.
Each SVI had a unique way of exploring and constructing graphs. Kamden and Guape
shared their experiences with exploring and constructing tactile graphics, while Bobbi
shared her experiences with exploration and construction of graphs through verbal
descriptions.

Guape mentioned that he used tactile graphics and the Audio Graphing Calculator
for graph reading purposes. When reading a tactile graphic, he stated, “I would start with
the title, the x and y axis and the...what they represent. The line itself that is the graph,
the main part. I mean the information itself that the line is giving” (Guape, interview,
May 2017).

Guape shared that unlike reading tactile graphics, reading graphs with the Audio
Graphing Calculator required entering information about the x and y axes before listening
to the output. He described how he uses the Audio Graphing Calculator to obtain
information from a graph.

For reading a graph with the [Audio Graphing] Calculator, I put in the
information of the x and y axis numbers and I think that they may be and usually
if it's something it's a line up and down there's the pitch of it, when it goes high it
changes the pitch. I move with the arrow with that and be able to point on the key of the arrow key I move on over, I want to point on that if I need to know what is that point or something. (Guape, interview, May 2017)

The processes Guape used to read graphs with both kinds of technology are examples of sequential, stepwise processes that individuals with visual impairments are known to use to understand spatial and graphical information.

Similar to Guape, Kamden’s vehicle of access to graphical information was through tactile graphics. He explained the process he uses to read bar graphs in tactile form.

I’d look at the title of the graph first and what the graph is going to be about, then I skip down to the side to look at the numbering on there. And then I start, look at the bottom and then after that I look at the data in the graph. (Kamden, interview, October 2017)

Bobbi’s strategies differed from the processes used by both Kamden and Guape to read graphs. Bobbi mentioned that she would rather listen to verbal descriptions by having graphs read to her. She mentioned that Google Sheets’ descriptions start with the shape of a graph, its coloring scheme, and lists the information pertaining to the referents at the end. She shared that the verbal descriptions given by Google Sheets aligns with the way she was used to viewing a graph before she lost her vision.

Not only did Kamden and Guape use tactile graphics for graph exploration, they constructed graphs in tactile form. For example, Guape discussed his experiences with constructing tactile graphics. “For my mathematics teacher I would ask what kind of information is needed. I would spot the points or set the points then go put the line on it,
those points...graphics, the paper thing....and I use Wikki Stix” (Guape, interview, May 2017). Guape constructs tactile graphics by asking the teacher what needs to be in the graph, and he uses Wikki Stix to connect the points he plots. Jeannine elaborated on the ways that Guape plots points when he constructs tactile graphics.

He uses push pins also and then graphs with Wikki Stix around it or push pins points through the Wikki Stix. For the most part I think he has Wikki Stix with $x$ and $y$ axis and then he graphs on that with push pins and the Wikki Stix. (Guape, interview with translation Via Jeannine, May 2017)

Jeannine described that Guape constructed tactile graphics by creating the axes with Wikki Stix, and after placing the axes, he used push pins to plot the necessary points.

Although Kamden and Guape constructed graphs in tactile form, the tools Kamden used to construct tactile graphics differed from the tools Guape used. Kamden constructed tactile graphics through graph paper, small foam circles for points, and tape for the axes.

Bobbi’s approaches for constructing graphs differed from Guape’s and Kamden’s. She explained the process of constructing graphs using Google Sheets. “You put in the two columns $x$ and $y$. You can put in town names and population and it’ll bring up a circle graph” (Bobbi, Interview, October 2017). Bobbi relied on Google Sheets and verbal descriptions as she was losing her vision, and graph descriptions gave her sufficient information to perform graphing tasks.

SVI experiences regarding graph comprehension. Each SVI reported a unique perspective regarding the level of comfort with graph comprehension tasks. For example, Guape mentioned that he found graphs to be challenging conceptually because of the
spatial reasoning involved. He elaborated, "In math we were doing angles, direction and magnitude so we had to know far as to go and how much up and how much to the right or left" (Guape, interview, May 2017). Jeannine shared further that Guape’s difficulties with gaining a solid understanding of direction and magnitude resulted from Guape’s tendency to perform multiple steps of an exercise in his head instead of using braille writing tools to keep track of each step he has taken in the process.

Unlike Guape, Kamden said that he found graphing to come easily. He attributed his success with understanding graphical information to simultaneous instruction given by his paraprofessional. “With me, she’s describing it while she’s showing me what the graph is like. I like it simultaneous, it usually gives me more of an idea of where basically every part of the graph is” (Kamden, interview, October 2017). He elaborated further on what his paraprofessional does to provide simultaneous instruction.

She basically shows me where this point would be and where that part would be and she would walk me through it. If this was a new concept the teacher would be showing it on the board while we have a tactile graph and she shows me where one point is and then how to do a certain thing. (Kamden, interview, October 2017)

The information Kamden shared about the simultaneous instruction approach used by his paraprofessional can serve as a guide for teachers who have SVI in their classes and are new to the idea of teaching their students how to use tactile graphics. It also serves as a reference for other SVI who are starting to learn about graphing in mathematics courses regarding techniques they may find helpful in understanding graphs along with their peers.
Similar to Kamden’s claim that comprehending graphical information did not pose any difficulties, Bobbi expressed that graphs were easy for her to understand conceptually because she had experiences with graphs before losing her vision. Her remaining memories from when she had full vision facilitated her understanding of the layouts of the graphs she is working with currently. The experiences SVI provided regarding textbooks, use of assistive technology, and graph comprehension differed from one SVI to another. These differences imply that there is not a standard set of tools that every SVI will use or a standard rate by which every SVI will learn the material. Therefore, it is beneficial for TVI and mathematics teachers to develop an awareness of and work with a variety of tools and strategies that are unique to the individual, rather than assume that SVI use specific tools or strategies to learn graphs successfully.

**Educators Supporting SVI to Learn Graphical Information**

I discuss the theme Educators Supporting SVI to Learn Graphical Information as it pertains to TVI facilitation of student understanding of graphical information, mathematics teacher facilitation of student understanding of graphical information, and paraprofessional facilitation of student understanding of graphical information.

**TVI facilitation of student understanding of graphical information.** While providing access through verbiage is beneficial to SVI in mathematics courses, TVI expressed that instruction may need to go beyond the verbal aspect. For example, Bonnie described her method for instructing students and ascertaining that they were on track to obtain correct responses to graphing questions. She described how she used the hand under hand method to give SVI an overview of a tactile graphic.
I just put my hand on the page and sit next to my student when I'm doing this. I put my hand on the page where I want him to look and I show him. I put my hand there and I say here, put your hand and look where I'm looking and he puts his hand on top of mine and feels for it and I pull back so he can see what we're talking about. (Bonnie, interview, May 2017)

Although Leah did not go into the amount of detail that Bonnie did in terms of the instruction she provided her students, she generally agreed that a combination of verbiage and hands-on instruction was necessary for SVI success with graphing. Leah stated,

To work with my student, I feel like we spend a lot of time orienting. He needed a lot of time to really have time for a graph and to know where stuff is placed and how to read it. (Leah, interview, June 2017)

Bonnie and Leah discussed the value of showing their students how to read graphs in a consistent and sequential manner. Bonnie emphasized the importance of the order in which she presents graphical information to her students.

I always start with the labels. They got to know the labels and then we look at the bottom. I have them go across the bottom and make sure they know what the numbers mean and then usually one of them is time and one of them is how many so let's start with time and let's find the first line going up and follow that line until we get to a dot and then we'll have one hand, probably the right hand stays on the dot and the left hand follows the line off to the left to find out the number. Then we compare, ok if the first line says 20 and the second line up over time, second period of time over we go up and it says 50 and then the next period of time we go up and then it says 30. They can go across and feel all the dots and see
if they're going up or down and then they get a lot better feel for what the actual dots are doing if they're increasing or decreasing over time. (Bonnie, interview, May 2017)

Leah also mentioned that it was to the student's benefit to orient them to the referents before introducing them to the functional part of a graph. To describe the order in which she taught her students to read tactile graphs, she shared,

The vertical data on this is what it means on this side. This is what the line underneath means. These are the dates or this is the amount of money. These vertical lines are in five degree increments. You'd have to tell him everything as it was labeled, point it out to him and have him be able to read it with you. (Leah, interview, June 2017)

In addition to talking about the kinds of instruction she provided and the order in which she taught her students to read tactile graphics, Bonnie stressed that she knew her students were obtaining correct responses when they felt comfortable in taking shortcuts from the approach she used.

Once they understand how the graphs are all set up the same, all the bar graphs are set up fairly similar and all the line graphs are set up fairly similar. At first when I taught them they would do what I had asked them to do and do it the way that I've showed them but then over time they would start taking shortcuts because they understood how the graph was set up. As long as they were getting it and getting the information and understanding what they were reading I consider that correct. I consider that correct as long as they're getting the right answers then I know that they're getting, they're figuring out how the graph works. Maybe they
do start from the point farthest on the left or maybe they look at the whole graph first and then they look first point and that's ok as long as they’re getting the information. So they take what I taught them and they do it for a while but then afterwards they feel more comfortable and they're able to find everything on their own. (Bonnie, interview, May 2017)

The tips Bonnie and Leah verbalized when teaching their students to read tactile graphics, as well as the procedure Bonnie shared regarding her approach to gauging her students’ abilities to use tactile graphics can serve as guides for teachers who are in the process of working with their students to learn how to use tactile graphics.

**Mathematics teacher facilitation of student understanding of graphical information.** TVI generally shared the instructional strategies they used for teaching tactile graphics to their students. However, not all SVI are in need of the simultaneous verbiage and hands-on instruction that Bonnie and Leah discussed above as being beneficial to their students, and Bobbi is an example. I delve into a specific case of a high school mathematics teacher (Kenny) supporting a single SVI in his class (Bobbi) to gain a deeper understanding of how a mathematics teacher supports an SVI in the classroom.

To set the stage for the layout of the classroom, Bobbi sat in the middle of the room and took notes with a pen and paper. She does not have any central vision and used the small amount of peripheral vision she had in order to focus on the white board and the notes she was taking at the time. The title of the lesson was Graphing Equations and Slope Intercept Form. Kenny was conscientious about making the material accessible for Bobbi through verbiage. As Kenny was discussing the concept of rise over run, he moved his hands up or down to indicate positive or negative rise and to the right or left to indicate a
positive or negative run. He complemented hand directions with explicit verbiage of numbers and directions (that students with normal vision would notice through sight) in order to provide Bobbi with the information she needed to understand the concepts that the rest of her classmates could grasp with vision.

Bobbi spoke about challenges she experienced with accessing graphs in class and the approaches Kenny used to address those challenges. She shared her issues with obtaining copies of tactile graphics ahead of time and the verbal cues Kenny gave to facilitate her following along with the rest of the class.

He just kind of talks through it … the rest of the class. He’s like if a point was 4,6, then he would say over 4, up 6, or over 6 and up 4 or something like that. And then I can just follow along with the rest of the class. (Bobbi, interview, November 2017)

Bobbi’s statement about Kenny’s verbiage during class was in alignment with Kenny’s initiative to describe all y-intercepts he wrote, as well as the direction and magnitude of the values associated with rises and runs when discussing slope.

Paraprofessional facilitation of student understanding of graphical information. The original structure of a triad was one SVI, the mathematics teacher serving the SVI, and the TVI serving the SVI. Because Merriam is much more involved than Lois with Bobbi’s graphing experiences, the structure of the triad that included Bobbi and Kenny was modified to include Merriam. The following account describes the portion of the observation following Kenny’s presentation to the class. Merriam and Bobbi met in a small storage room located in the basement of the building after the lesson ended. Merriam expressed that obtaining the braille version of the textbook and reading
the problems aloud were ways in which she supported Bobbi. Merriam shared that she read the problems out loud to Bobbi to facilitate Bobbi’s knowledge of the Nemeth Code as she followed along in the book. Bobbi utilized the textbook and Merriam’s reading aloud to gain access to the homework exercises. But in order to show her work to the homework exercises, Bobbi used the Graphic Aide. To mark the origin, Bobbi stuck a long pin into the center of the board, the head of the pin sticking out through the top of a tube situated at the origin. In order to show the slope of the line, she plotted points by first using her finger to find the origin, then repeatedly counted from the origin following the $y$-axis either up or down depending on the magnitude of the $y$-coordinate and its sign, then counted to the right or left depending on the magnitude and sign of the $x$-coordinate. She used the intersecting lines on the grid, putting a pin at each point, and connected pins to one another with rubber bands.

Merriam and Bobbi communicated through the first two problems. Merriam read the exercise, and Bobbi talked through each part as Merriam listened and gave input as necessary. Merriam reinforced that the slope was 2 and the $y$-intercept was 4 by verbalizing the values as Bobbi followed along. Merriam asked Bobbi how she would turn the slope into a fraction, and Bobbi demonstrated that she knew how to do this by saying, “Wouldn’t it be the $m = 2$, no, 2 over 1” (Bobbi, observation, November 2017). Bobbi was mindful of the rise over run concept as she was explicit about giving the slope as the rise of 2 over the run of 1. Merriam agreed, “2 over 1” to reinforce that Bobbi was correct. When Bobbi moved the pin on the graphing board up two points and stopped, she demonstrated that she knew something she did was incorrect, though she did not know what was incorrect yet, when she said, “Whoops.” Merriam pointed out that Bobbi was
not in the correct spot and needed to move the pin one more point in the positive
direction on the x-axis. To guide Bobbi to the correct spot, she said, “You were there, and
then you’re going to go over 1, perfect. And then do the same thing again from that point,
up 2, over 1.” Merriam reminded Bobbi of the points she needed to plot using the
Graphic Aide. “We would do the up 2 and right 1 from your 0. And then go up again, up
2 and over 1 from that point to create your line” (Merriam, observation, November 2017).
Merriam observed that Bobbi did not move over one point to the right and let Bobbi
know of the mistake with, “That’s up 2.” Bobbi showed Merriam that she moved over
one point and asked if she was on the correct coordinate. Merriam guided Bobbi to the
next step of the problem by saying, “Yeah, then you can take your rubber band and make
your line” (Merriam, observation, November 2017). The dialogue between Merriam and
Bobbi served as an example of a paraprofessional’s approach to support a student when
working with graphical information. While Merriam supported Bobbi through reading the
homework problems and reminding her of the slope and the intercept, she encouraged
Bobbi to go through each step of the exercise verbally and encouraged Bobbi to work
toward the correct answer rather than doing the exercise for Bobbi and assuming Bobbi
would know how to do it.

Bobbi is fortunate in that she has a supportive group of teachers working with her.
Bobbi commented on how Merriam might support her when teachers would have
difficulty understanding what she indicated as her response to an exercise using the
Graphic Aide. Bobbi indicated that Merriam would communicate to the teacher that
Bobbi’s answer was what she intended it to be. She replied, "Since [Merriam]’s right there
with me, she said if we ever have a problem, which we haven’t at all yet, she said she can
talk to him and just say I was right there and yes, it was 4 ½“ (Bobbi, interview, November 2017). Bobbi expressed that Merriam played the role of an advocate as well as an instructor.

**Discussion**

In this section, I discuss the ways in which the findings align with and add to existing literature on SVI and graphing (Dulin & Hatwell, 2006; McKenzie & Lewis, 2008; Millar, 1994; Papadopoulos et al., 2011). The section is organized around the themes and research questions of the study.

**Teacher Perceptions of Graph Accessibility and Comprehension for SVI**

Research Question One centers on teachers’ perceptions of how they support SVI to learn graphical information. Teacher Perceptions of Support for SVI to Access and Comprehend Graphical Information emerged as a theme, and the subthemes centered on mathematics teachers’ and TVI perceptions of access concerns and teachers’ perceptions of the value of paraprofessionals and mathematics consultants as sources of teacher training. The responses given by TVI differed from the responses given by mathematics teachers regarding the concerns they had around SVI and graphical information. For example, Kenny emphasized that he was concerned that the time it took Bobbi to complete graphing tasks was significantly longer than the time it took the rest of her peers. Meanwhile, Lois was concerned about Kamden’s ability to complete graphing tasks independently.
TVI experience serving SVI creates awareness of the unique needs SVI have (Correa-Torres & Howell, 2004; Suvak, 2004). The greater level of awareness of TVI with respect to their students' accessibility needs adds to the literature (Correa-Torres and Howell, 2004; Kahn and Lewis, 2014; Suvak, 2004). TVI receive training specific to the needs of SVI, whereas mathematics teachers in general education programs do not. The concerns and issues expressed by mathematics teachers parallel the literature discussed previously (Millar, 1994; Pritchard & Lamb, 2012; Zebehazy & Wilton, 2014a; 2014b). For example, Natty's concerns with Guape's access to the textbook and teacher-prepared material on time was in alignment with the concerns the teacher in Pritchard and Lamb (2012) expressed about the delay of access to instructor-created material and the textbook potentially having a negative impact on her student's ability to learn geometry along with the other students. Millar's (1994) theory of spatial representation discussed the amount of time and effort required for individuals with visual impairments to learn spatial concepts due to the sequential, self-referencing strategies they need to use on a constant basis before they are able to integrate information by connecting components to one another in a holistic manner.

Leah’s elaboration on the specifics of formatting issues with tactile graphics adds to previous literature. Zebehazy and Wilton (2014a; 2014b) mentioned density of tactile graphics as being generally problematic for their students, but did not mention the challenges associated with deciphering the textures of the lines. Leah discussed the issues with graphs produced in textbooks her students used as she said, “They often are not clearly marked so that you can feel the difference between the lines” (Leah, interview, June 2017). She went on to discuss the challenge of making all of the lines texturally
identical to one another. “They use the same tufting to draw the diagonal line that shows the data, same materials are used to create the lines on the graph itself. It gets blurred” (Leah, interview, June 2017).

The information participants provided about the training they received adds to existing studies on the role of the paraprofessional for instructing SVI (McKenzie & Lewis, 2008). Teachers expressed that they learned the skills they needed to teach graphs to SVI by researching on their own initially, and then communicating with one another, the paraprofessionals, and the mathematics consultant. Mathematics teachers and TVI were in agreement that paraprofessional educators play essential roles in helping them develop skills to teach SVI to use graphical information. McKenzie and Lewis (2008) studied the roles of TVI and paraprofessionals in providing instruction to SVI. These scholars reported that paraprofessionals act as intermediaries in the process of instruction for SVI. TVI generally provide instruction to paraprofessionals, and paraprofessionals reinforce the instructional methods they obtained from the TVI. Lois’ account about Merriam was in contrast to the responses given by the TVI in McKenzie and Lewis (2008). By saying, “Not her making it herself, someone making the graph for her” (Lois, interview, September 2017), Lois emphasized that Merriam helped her realize that both teachers were responsible for producing tactile graphics for Bobbi.

TVI credited the mathematics consultant for providing them with tips on how to instruct their students about graphical information. Lydia mentioned that she appreciated being refreshed on the Audio Graphing Calculator because she knew she could take the information she learned from the session with the consultant to some of her students who utilized the Audio Graphing Calculator. Lois mentioned that the consultant provided
guidance to her on how to make tactile graphics for students, as well as how to teach students to make their own tactile graphics.

**SVI Experiences with Accessing and Comprehending Graphical Information**

Research Question Two centers on how SVI in high school mathematics courses learn graphical information. SVI Experiences Accessing and Comprehending Graphical Information emerged as a theme, and the subthemes were focused on SVI challenges with access to graphs with assistive technology, accessing graphs in textbooks, and their experiences comprehending graphs. With each form of assistive technology comes a unique set of challenges for learning how to use it. For example, Bobbi (and other individuals with late onset blindness) do not have prior knowledge of the braille code and how to use their hands and fingers to read braille appropriately. They do not have opportunities to develop and refine their sense of touch in the same way that individuals with total and congenital blindness develop their sense of touch. Individuals with late onset blindness have fingers and hands that are not as attuned to differences in changes in size and shape of tactual objects, and the braille code is filled with letters and numbers that may look and feel similar but are, by their nature, very different from one another (Millar, 1994). On the other hand, Kamden and Guape were born with visual impairments severe enough that neither are able to read large print, and both students emphasized that reading and constructing graphs with assistive technology that produced tactile graphics was the most reasonable means for them because of the skills they developed to read braille. Dulin and Hatwell (2006) and Papadopoulos et al. (2011) have shown that onset of visual impairment influences the ease with which individuals with visual impairments are able to construct tactile representations of paths and gauge the relative positions of
objects around them as they navigate. These researchers contended that individuals with late onset blindness were able to construct tactile representations of paths and navigate spaces more quickly and with fewer errors than those with congenital and early onset blindness. But given time, practice, and positive reinforcement, individuals with congenital blindness were able to construct mental representations of paths with the same level of efficiency as their counterparts with early and late onset blindness (Dulin & Hatwell, 2006). For example, Kamden (a student with congenital visual impairment) was able to comprehend graphs effectively because his paraprofessional provided reinforcement of how to explore tactile graphics. He stated, “With me, she’s describing it while she’s showing me what the graph is like. I like it simultaneous, it usually gives me more of an idea of where basically every part of the graph is” (Kamden, interview, October 2017). The findings from Dulin and Hatwell (2006) and Papadopoulos et al. (2011) regarding the production of tactile representations and navigation through a space suggest that SVI with total and congenital blindness may have additional challenges that SVI with previous visual experiences do not have when in the initial stages of learning to use graphs, but SVI with total and congenital blindness will be able to overcome challenges and understand graphs as well as their peers if they are motivated and equipped with the appropriate combination of pedagogical and technological support.

Although Dulin and Hatwell (2006) and Papadopoulos et al. (2011) discussed the influence of an individual’s onset of blindness with respect to constructing tactile representations of paths and spatial navigation, they did not discuss the influence of onset of blindness with regard to comprehending graphical information. To my knowledge, this study is the first to address this issue. Onset of visual impairment may have an influence
on the abilities of SVI to read, construct, and apply graphical information in a variety of contexts. For example, Bobbi and Kenny discussed that Bobbi did not have any difficulties with learning about graphs along with her peers because of the visual memories she still retains. However, Guape mentioned that he found graphing arduous due to the type of spatial reasoning required to work with angles. On the other hand, individual differences also need to be taken into account. Kamden claimed that graphing was an easy task for him, though he and Guape were similar to each other in the amount of blindness they experienced. These findings suggest that it would be beneficial to conduct studies that focus on onset and amount of blindness as potential influences for comprehending graphical information.

Issues students reported with regard to their textbooks are unique to this study. In Pritchard and Lamb (2012), the student had no textbook to use, so the teacher created group activities in which the student's classmates read the textbook aloud. Spindler (2006) was similar in that the taped textbook was of no use to the student, so the tutor read the textbook and problems aloud as well. However, Kamden's account of issues he experienced with his textbooks, and the actions his paraprofessional took to make the textbook material accessible, differ from what has been reported from existing literature.

Millar (1994) stressed that, although children with visual impairments tend to learn spatial concepts primarily through self-referencing cues and systematic exploration with their hands, teachers still need to take individual differences into account when providing instruction to read maps and travel routes. She mentioned that prior knowledge differs from one individual to another regardless of whether or not an individual has a visual impairment. Yet individuals with an absence of vision need more consistent and
direct instruction than do individuals with normal vision, especially when they are in the process of connecting pieces of information from unfamiliar concepts to information they have learned in the past. Individuals with visual impairments could encounter issues with learning a new assistive technology as Bobbi has had to do when she transitioned from reading graphs with vision she previously had and using Google Sheets to having to read and construct graphs using the Graphic Aide. Individuals with visual impairments could also have issues with content, similar to Guape's difficulties with the spatial reasoning required to understand graphs. Regardless of the issues an individual with a visual impairment has with a new concept, Millar stressed that it is vital for instructors to be aware of the needs of SVI and teach according to these needs, and at the same time, encourage SVI to learn new concepts given adequate support. Specific to graphing, Zebehazy and Wilton (2014a; 2014b; 2014c) mentioned that TVI and SVI were similar in their regard for the importance of direct instruction for both students with total blindness who use tactile graphics and students with low vision who use print graphics. Kamden spoke about the benefit of simultaneous hands-on instruction and verbiage his paraprofessional provided as he was reading through a tactile graphic.

Bobbi’s needs for accessing graphs in class were different from both Guape and Kamden, as well as other examples discussed in the literature (Dick & Kubiak, 1997; Zebehazy & Wilton, 2014a; 2014b; 2014c). Kamden and Guape reported that they needed both verbal instruction from the mathematics teacher and hands-on guidance from their paraprofessionals when graphs were being discussed in class. However, Bobbi benefited from verbal descriptions alone. Millar (1994), Dick and Kubiak (1997), and Zebehazy and Wilton (2014a; 2014b; 2014c) emphasized that hands-on instruction was
necessary for both students with blindness and students with limited vision to have sufficient access to graphical information. However, Millar stressed that individuals with prior visual experiences take less time than individuals with total and congenital blindness to process information as though they can still see it -- skipping the sequential processing and integrating parts immediately -- even after they lose their vision. She stressed that they may not need the amount or type of systematic instruction individuals with congenital or total visual impairments are likely to require to comprehend spatial information. Millar (1994) also mentioned that, depending on the individual, memories of visual experiences can fade over time, especially for those who continue to lose their vision, so it is important to provide these individuals with assistive technology that takes advantage of their remaining senses. While a certain amount of direct and hands-on instruction is likely to be beneficial for a majority of SVI, Bobbi and Kenny expressed that verbal cues are enough for her to follow along with tactile graphics as he discusses them. Bobbi's case suggests that instructional strategies may vary from student to student depending on the student's prior visual experiences.

**Educators Supporting SVI to Learn Graphical Information**

Research Question Three centers on educators’ support of SVI in high school mathematics courses. Educators supporting SVI to learn graphical information emerged as a theme, and I demonstrated how TVI support SVI to learn tactile graphics, as well as the support Kenny and Merriam provided Bobbi with graphing. The ways in which TVI described their approaches to student teaching are in alignment with literature from Dick and Kubiak (1997), Millar (1994), and Zebehazy and Wilton (2014a; 2014b). SVI need assistive technology to have sensory access to graphs, but teacher involvement provides
students with the tools to comprehend graphs appropriately and independently. My study is the first to provide detail on how teachers show their students to use graphs regarding the positions of their hands when reading graphs and the types of behaviors students exhibit once they become more comfortable with graphing tasks. Bonnie’s explanation of how her students behave when they become more confident in performing graphing tasks correctly provides insight on the signs to be aware of for student progress in graph comprehension. She mentioned that students would show they were progressing with reading through a graph by demonstrating that they did not have to read every component.

At first when I taught them they would do what I had asked them to do and do it the way that I've showed them but then over time they would start taking shortcuts because they understood how the graph was set up. (Bonnie, interview, May 2017)

While TVI shared their instructional approaches for tactile graphics, Kenny discussed that the pedagogical approaches he used with Bobbi centered on verbalization of graphical information. Kenny consistently repeated himself when referring to visual content he put on the white board and referred to visual content by its mathematical terminology rather than using words such as “this” or “that” to communicate what was being put on the white board. His communication style therefore paralleled that suggested by Dick and Kubiak (1997), Quek and McNeill (2006), and Spindler (2006), which suggest that SVI need repetition of words associated with visual entities. Though Bobbi did not talk during the lesson, she took notes as Kenny spoke. She stressed that Kenny’s
style of teaching was helpful to her when she was not able to see everything on the white board and was provided with tactile graphics.

The ways in which Merriam supports Bobbi with access to and comprehension of graphs provide additional information to the existing body of literature that centers on SVI learning (Barth, 1983; Dick & Kubiak, 1997; Millar, 1994; Quek & McNeill, 2006), as well as how paraprofessionals support SVI in the classroom (McKenzie & Lewis, 2008). While McKenzie and Lewis (2008) focused on teachers’ accounts of the roles of paraprofessionals, this study demonstrates the benefit of the paraprofessional from the voices of both the student and the teacher as they communicate about graphical information. For example, Merriam would reinforce when Bobbi was correct and wait until Bobbi realized that she was not on the right track before intervening to help her get back on track. Merriam intervened when Bobbi was attempting to figure out how many points to count to the right when graphing the slope of $2/1$, Bobbi expressed, “Whoops.” when she realized she did not count to the right one space on the $x$-axis after she went up two points on the $y$-axis. Merriam intervened with: “You were there, and then you’re going to go over 1, perfect. And then do the same thing again from that point, up 2, over 1” (Merriam and Bobbi dialogue, observation, November 2017).

Merriam gave her own account of how her support was beneficial for Bobbi to access the material. Bobbi’s newness to the Nemeth code caused difficulty in getting through the problems in a timely manner, so Merriam would read the problems aloud when necessary, and Bobbi would follow along in her braille book. Bobbi agreed as Merriam spoke about the challenges with learning the Nemeth code and the benefit of reading the problems aloud as Bobbi followed along. Bobbi expressed that she realized
Merriam was willing to advocate on her behalf when issues arose regarding her responses to assigned homework problems. She mentioned that although neither she nor Merriam experienced a situation where her teachers had issues in understanding what her responses were to the exercises or how she arrived at the responses she gave, Merriam would be willing to intervene by speaking with any of Bobbi’s teachers if a situation presented itself. I now discuss the limitations and implications of the study.

**Limitations of the Study**

Each study has its own set of limitations, and my study is no different from the rest. One limitation is the sample size, in particular, the number of TVIs (four) as compared to the number of mathematics educators (two). TVIs gave a variety of accounts regarding the technologies and instructional strategies that benefited the students they served. The mathematics educators, in contrast, dealt with only one student for one year. Both mathematics educators reported that they were learning on an “as needed” basis as they recognized their students’ needs. Had I been able to speak with mathematics teachers who had worked with more than one SVI, or the same SVI for more than one year, I may have gotten a more thorough account of what the mathematics teachers learned over time in terms of the challenges in assistive technology and instructional strategies, from one year to another with a single student, or from one student to another for multiple students.

Another limitation existed in regard to the emerging theme of the paraprofessional. I designed the study with the expectation that only mathematics educators and TVIs were responsible for serving SVIs. In my experiences as a high school student, I communicated directly with my mathematics teachers in large part, and when
necessary, communicated with the TVI in the case that a concept was not clear to me after speaking with the mathematics teacher. While my paraprofessionals produced the materials, I did not communicate with them to the extent that I had with the TVI that served me at the time. I was not aware that students and teachers alike would consider paraprofessionals as beneficial to the success of SVI with graphing.

**Implications for Future Research**

While I conducted the study, I realized that SVI were served not only by mathematics educators and TVI. The math consultant and the paraprofessionals also played roles in serving this populace of students. Few states have a mathematics consultant who provides resources for SVI in mathematics courses. Future research is needed to understand paraprofessionals' perceptions of how SVI access and comprehend graphs when in high school mathematics courses, as well as to understand the types of resources teachers utilize, due to the scarcity of mathematics consultants. Research that centers on paraprofessionals’ perceptions and resources in the absence of a mathematics consultant would further inform which resources could be available and may serve as a reminder that mathematics consultants are needed in other states as well as the state where I conducted the study.

Mathematics teachers and TVI who currently serve SVI expressed that they were informed of what these students need through consultations with teachers who had prior experience with assistive technology and instruction from which the students benefited. Mathematics teachers and TVI expressed that training sessions the consultant provided were informative regarding assistive technologies and instructional strategies SVI need in order to access and comprehend graphs in high school mathematics classes. Many
teachers with credentials to serve SVI have not received similar credentials in mathematics, so they may not be as skilled in the mathematical knowledge that is necessary for teaching graphs or the Nemeth Code (DeMario, Lang, & Lian, 1998; Kapperman & Sticken, 2003). Therefore, it may benefit TVI and paraprofessionals who serve SVI in high school mathematics courses to consult with their students’ mathematics teachers for the purpose of gaining basic content knowledge of the concepts covered in the mathematics course. A possible opportunity for research could focus on communication barriers TVI and paraprofessionals come upon as they consult with mathematics teachers about course content. Learning assistive technology could be a potential barrier to instructors of K-12 mathematics courses, given a lack of experience with technology specific to SVI and time constraints associated with teaching. Future research should address the most efficient ways to help teachers learn assistive technology in order to support SVI.

Previous literature (Dick & Kubiak, 1997; Millar, 1994; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c), and a majority of participants, offered that tactile graphing and direct, hands-on instruction are the main tools that should be used to provide SVI with proper access to and comprehension of graphical information. However, it is important to keep individual differences in mind when providing SVI with techniques to learn graphical information. For example, the combination of hands-on orientation and verbiage TVI reported to provide their students differed from the instruction Merriam and Kenny provided Bobbi during the observation, which was mainly verbal in nature. An avenue for future research could be to gain a deeper understanding of the support teachers provide students with varying levels and onsets of
blindness, ranging from total and congenital blindness to moderate and late onset, as they learn alongside their peers in a classroom setting.

References


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CHAPTER 5. GENERAL DISCUSSION AND CONCLUSIONS

This dissertation addressed the question: How do SVI access and comprehend graphical information in high school mathematics courses, and how do teachers support needs SVI have in regard to accessing and comprehending graphs? Literature surrounding SVI and graphing (Barth, 1983; Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c) shows that, for SVI in high school mathematics courses, learning about graphical information happens very differently than it does for students with normal vision, and teachers who serve SVI employ unique instructional strategies that accommodate to the ways in which SVI learn. The findings that emerged from the studies I conducted were in accordance with, and also added to, this body of literature. I developed a conceptual framework to guide my thinking regarding how SVI are likely to access and comprehend graphs in high school mathematics courses. I further informed the conceptual framework with data I gathered and analyzed through a multistate survey of TVI, along with interviews with TVI and SVI and a classroom observation involving a single SVI and the teachers who supported her needs.

After reviewing the literature and conducting these studies, I draw three implications. To begin, SVI access graphical information in ways that differ from the ways in which students with normal vision access graphical information, and variability exists within the SVI population for accessing graphical information. Second, SVI are unique, as a group and as individuals, in how they comprehend graphical information. Finally, the approaches teachers take to support SVI with graphical information in high
school mathematics courses differ from the approaches they take to serve students with normal vision.

**Implications for Access to Graphical Information for SVI in High School Mathematics Courses**

As discussed in the development of the conceptual framework (Chapter 2 of the dissertation), access to graphical information is possible for SVI in high school mathematics courses under two conditions. SVI need to be provided with adequate assistive technology and instructional strategies. TVI need training in the areas of assistive technology and instructional strategies in order to teach SVI in ways that take their limited visual experiences into consideration. I elaborate on the implications of assistive technology, instructional strategies, and teacher training necessary to accomplish accessibility of graphical information for SVI in high school mathematics courses.

**Implications for Assistive Technology**

There exists a variety of assistive technologies available for SVI to access graphical information (American Printing House for the Blind, 2016; Davison, 2013; Ferres, Lindgaard, Sumegi, & Tsuji, 2013). Of the assistive technologies available to access graphical information, Barth (1983), Dick and Kubiak (1997), Millar (1994), Quek and McNeill (2006), Spindler (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c) claimed that tactile graphics serve as the primary and preferred method for SVI to access graphical information. Davison (2013) asserted that it is best to introduce SVI to tactile graphics before introducing them to technology that produces graphs through sonification or verbal descriptions for the purposes of point-by-point exploration. However, he mentioned that teachers and students also need to be aware that assistive technology that
produces sonified graphics is becoming more popular because of the improvements in tools that produce graphs via sonification. Ferres et al. (2013) mentioned that natural language assistive technology (NLAT) provide verbal descriptions of graphical information using language that is appropriate only for advanced graph users.

**Student views.** Guape and Kamden used tactile graphics on a regular basis. Kamden used only tactile graphics, while Guape had been exposed to both tactile graphics and the Audio Graphing Calculator. Guape said he was introduced to tactile graphics and the Audio Graphing Calculator, but preferred to use tactile graphics over the Audio Graphing Calculator. Jeannine (Guape’s paraprofessional and translator during the interview session), explained that Guape’s teachers needed to carve out additional time to assist him with learning how to use the Audio Graphing Calculator, and even then, the instruction was not sufficient for him to effectively use the tool.

Guape and Kamden experienced visual impairment since birth and were fluent braille users. On the other hand, Bobbi’s visual impairment occurred when she was ten. Unlike Kamden and Guape, Bobbi had been introduced to tactile graphics after being introduced to graphs through Google Sheets, a program that provides the print graphic and its verbal description. She preferred accessing graphical information through Google Sheets rather than accessing graphical information with the Graphic Aide or embosser-produced tactile graphs. She expressed that peer distraction, time, and independence were issues she encountered when using tactile graphics. Millar (1994) emphasized that the Nemeth code (the braille code for mathematical notation) is difficult for individuals to learn if they have had visual experiences, because they relate braille symbols to print
letters and have to rely on their sense of touch rather than their sense of vision to learn how to read braille to begin with.

In the published literature, Barth (1983), Dick and Kubiak (1997), Millar (1994), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c) suggested that SVI are likely to access graphical information through tactile graphics over other forms of assistive technology, and each SVI should have tactile graphics at their avail. Based on the interviews and observation discussed in Chapter 4, Kamden and Guape (the students with early onset visual impairments) were tactile graphics users, while Bobbi preferred to utilize verbal descriptions. The findings in Chapter 4 suggest that, while tactile graphics serve as the most common means of assistive technology SVI use to access graphs, individual differences exist within the SVI community regarding the assistive technologies they prefer to use, and preferences could be based on level and timing of visual impairment.

**Implications for Instructional Strategies**

SVI will be able to use assistive technology for graphing in an effective manner only if they are provided with sufficient instruction to use it (Millar, 1994). The instructional strategies from which SVI benefit with regard to graphical information differ from instructional strategies for students with normal vision. In Chapter 2, I defined instructional strategies as “pedagogical techniques teachers use with graphs that have been generated through appropriate assistive technology” (p. 42). Literature surrounding individuals with visual impairments and graphing (Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c) provides guidance on the kinds of instruction teachers should provide SVI as they are using tactile graphics.
These scholars suggested that providing instruction to SVI requires more than simply handing a student a tactile graphic and describing its components. In addition to providing SVI with a tactile graphic, Dick and Kubiak (1997), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c) contended that SVI benefit from pedagogical practices in which instructors use their hands to guide the student through a tactile graphic while verbalizing each component with which the hand is in contact using mathematical terminology rather than vague language as “this,” or “that.” Instructors also should be aware of the progress their students are making when exploring tactile graphics. Instructors should encourage their students to explore tactile graphics independently. These researchers explained that instructors should allow students to explore a tactile graphic and verbalize their exploration processes, watching the process as it happens and intervening when both the teacher and student deem necessary.

**Teacher survey data.** My data were in alignment with Dick and Kubiak (1997), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c). TVI reported that they disagreed with items that stated that students would be able to use tactile graphics through the instructor’s provision of the tactile graphic alone or through verbiage alone. The data further inform the literature, as well as the conceptual framework. Beyond demonstrating how teachers should provide instruction to SVI, the findings from interviews with TVI illustrated how they supply SVI with simultaneous hands-on guidance and verbal cues. Bonnie and Leah discussed the approaches they used to teach their students to use tactile graphics. Leah mentioned that using both hands to orient her students to a tactile graph helped her students understand the relative placement of one component to another.
Bonnie seconded Leah by delving into more detail about how and why it is necessary to orient students to tactile graphics with a combination of hands-on instruction and verbiage. She explained that she would sit next to a student, place her hand on a component (e.g., the x-axis), place the student’s hand on top of her own, and move her hand along the component, while explaining to the student. After introducing the student to all of the components of the graph, Bonnie would move her hand from underneath the student’s hand so that the student could explore the graph independently. Bonnie said that she was able to gauge when her students became more independent with reading tactile graphics. She commented that her students demonstrated that they were becoming more fluent in using tactile graphics when they demonstrated that there exist different categories of graphs, (e.g., line, bar, circle), and each category requires a different form of exploration, but all graphs within a specific category can be explored in the same way.

The literature (Dick & Kubiak, 1997; Quek & McNeill, 2006; Zebehazy & Wilton, 2014a; 2014b; 2014c), and the accounts of the participants suggest that, when instructing SVI to use tactile graphics, instructors should provide the tactile graphic, guide students using hands-on orientation, verbalize each component as the hand makes contact, and encourage students to understand the layout of a tactile graphic independently.

Implications for Teacher Training

I define teacher training in the conceptual framework as “the knowledge and skills teachers acquire when earning their degrees as educators along with subsequent professional development opportunities” (p. 37). Kahn and Lewis (2014) and Rule, Stefanich, Boody, and Peiffer (2011) reported that general educators are oftentimes ill-prepared to teach students with visual disabilities because they did not receive adequate
training in teacher education programs. In many programs that offer the TVI credential, the Nemeth Code and tactile graphics are not taught with the degree of rigor or frequency that give TVI the confidence or competence to be of value in teaching mathematics to their students (DeMario, Lang, & Lian, 1998; Kapperman & Sticken, 2003). According to Correa-Torres and Howell (2004) and Suvak, (2004), some aspects of the TVI credential include ordering braille and large-print textbooks, travel skills, and negotiating with parents and guardians regarding resources SVI need, and TVI acquire more extensive training on the Nemeth Code, tactile graphics, and assistive technology through professional development opportunities. According to these researchers, the type of professional development opportunities offered throughout the United States depend on the state of residence. According to Louisiana’s professional development Web site (PDRIB, 2018) and Colorado’s professional development Web site (Colorado Department of Education, 2017), professional development opportunities include conferences, workshops, and courses designed to teach anything from social skills to financial wellness to assistive technology and instruction.

Given what I found in the literature around training for teachers who serve SVI (Correa-Torres & Howell, 2004; PDRIB, 2017; Suvak, 2004), I focused on the professional development aspect of teacher training for mathematics teachers and TVI who participated in the study. Participants described personal experiences that reflected on, and added to, literature on training for teachers who serve SVI. For example, mathematics teachers Natty and Kenny said that they did not receive any training related to teaching students with visual impairments in their general education programs for earning the mathematics credential, which aligns with the findings Kahn and Lewis
(2014) reported on the lack of preparation for teaching individuals with visual impairments.

Natty reported that Jeannine (see Chapter 4), was a wonderful resource for obtaining information about the assistive technology Guape used to access materials Natty prepared for Guape. In addition, Kenny (Bobbi’s mathematics teacher) stated that Merriam (Bobbi’s paraprofessional) pointed out to him that he needed to complement content he wrote on the board with verbiage. TVI stated that they deemed consultation with their students’ paraprofessionals and workshops with mathematics consultants as the most beneficial resources for training in creating tactile graphics and teaching SVI how to use them. Overall, the mathematics teachers and TVI agreed that the information they acquired pertaining to assistive technology and instruction for graphing came in large part from individuals who have had prior experiences serving many students, including the SVI with whom they currently work. McKenzie and Lewis (2008) reported that TVI and paraprofessionals often share similar roles in providing instruction to SVI, though their focus was not specific to graphical information. To my knowledge, my dissertation is the first piece of literature, both in the corpus of information on SVI and graphing, to provide accounts from TVI on the value of paraprofessionals in their professional development training.

Implications for Comprehension of Graphical Information for SVI in High School Mathematics Courses

I now transition from implications regarding accessibility to implications regarding comprehension of graphical information. For students with normal vision, Pinker (1990) proposed a theory of graph comprehension that suggests that individuals focus on a graph’s function before they begin to focus on its referents, and Shah and
Carpenter (1998) conducted a study that also suggested that individuals with normal vision explore the functional part of the graph before they focus attention on the referents. To my knowledge, no theory exists for individuals with visual impairments to explain the processes SVI use to comprehend graphical information. Millar’s (1994) theory of understanding spatial representation stands as the most comprehensive account of how these individuals understand a variety of spatial representations, so I have used her theoretical basis as the springboard for developing the portion of the conceptual framework that addresses comprehension.

This portion of the conceptual framework is cyclical. The cyclical structure indicates what Millar (1994) theorized about the approaches individuals with visual impairments employ to understand a given spatial representation. According to Millar (1994), comprehension is a repetitive process that requires multiple iterations of sequential encoding and integration. Individuals with visual impairments encode a spatial representation into memory not as the whole spatial representation, but as a group of symbols with no connection to one another as their hands move along the representation from left to right and from top to bottom; I refer to this process as sequential encoding. Integration, as it pertains to the conceptual framework, implies that individuals with visual impairments begin to integrate the parts of the spatial representation into a whole when they recognize that each piece of the representation is connected to other pieces, but they still may not have a solid understanding of how or why the pieces of the representation are connected as they are. For individuals with visual impairments, comprehension begins to take place once they are able to identify a specific representation and apply the representation in a meaningful context. With each spatial
representation, the process starts anew – first with sequential encoding, next integration, and then comprehension.

With regard to graphical information, Pinker (1990) (for individuals with normal vision), and Zebehazy and Wilton (2014b) (for SVI) agree that graph comprehension encompasses activities such as reading through a graphical representation with the intent to glean information from it, as well as graph construction. Barth (1983), Dick and Kubiak (1997), Ferres et al. (2013), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c) suggest that individuals with visual impairments explore graphs in a manner that differs from individuals with normal vision. These researchers noted that individuals with visual impairments read graphs by focusing their attention on the referents, such as the axes and labels, before drawing attention to the function. Zebehazy and Wilton (2014b) suggested that graph comprehension for SVI entails exploring a graph piece by piece in a counterclockwise manner before beginning to understand it as a whole. In Chapter 4, I provided insight from experiences about how SVI read and construct graphical information, as well as resources that have helped them to understand graphical information and issues unique to the SVI populace.

Student Views

SVI Kamden and Guape tended to comprehend graphical information in a piecewise manner. Both students mentioned that they read tactile graphics by reading the title first, then focusing on the information associated with each axis before they began to explore the function. Guape focused first on the referents associated with the x-axis before focusing on the referents associated with the y-axis. In contrast, Kamden explored tactile graphics in the reverse order by focusing on the y-axis referents before focusing on the x-axis referents. Bobbi, on the other hand, mentioned that she relies on verbal
descriptions from Google Sheets to understand the contents of a graphic, and she mentioned that Google Sheets gave an overview of the shape of the graph before going into more detail about specific components. Guape and Kamden mentioned that they constructed tactile graphics by plotting points with pins and then using Wikki Stix or tape to connect the pins to one another. Bobbi mentioned that just as she uses Google Sheets to elicit verbal descriptions, she also uses Google Sheets for graph construction.

Bobbi, Kamden, and Guape also talked about their experiences with the benefits and barriers associated with graph comprehension for SVI. Kamden attributed his abilities to comprehend graphs successfully to the instructional approaches his paraprofessional used, which entailed the combination of verbiage and hands-on instruction. Bobbi attributed her success with graph comprehension to the memories that she retained while working with graphs before she lost her vision. Unlike Kamden and Bobbi, Guape stressed that he had issues comprehending graphs because he struggled with understanding how each component relates to one another in a spatial sense. My participants’ experiences with graph comprehension were in agreement with Millar’s (1994) theory of understanding spatial representations. She stressed that, while SVI are likely to comprehend space in a piecewise manner as Kamden and Guape did when reading tactile graphics, individuals in the SVI community with prior visual experiences demonstrate they operate more like individuals with normal vision. She also stressed that individuals with visual impairments demonstrate differences in the quality with which they comprehend spatial information. Although Guape and Kamden are similar in their level and onset of visual impairment, Guape mentioned that he struggled with graphs, while Kamden said graphs did not cause any problems for him conceptually. The work of
Millar (1994) and the accounts of participants from Chapter 4 suggest that graph comprehension approaches are likely to differ from one SVI to the next.

**Implications Regarding Teacher Support for SVI to Access and Comprehend Graphical Information**

Now that I have discussed the ways in which SVI access and comprehend graphical information, I draw from Chapters 3 and 4 to summarize teacher support for SVI in high school mathematics courses. As I reported in Chapter 3, over 90% of the TVI who participated in the survey responded that they were likely to introduce their students to tactile forms of assistive technology or both tactile and audio forms, but not to audio forms of assistive technology only. This finding was in alignment with Dick and Kubiak (1997), Millar (1994), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b; 2014c), who reported that tactile graphics are the most common form of assistive technology SVI use.

In Chapter 4, Bonnie and Leah explained that they taught their students how to read tactile graphics in the sequential manner that Millar (1994) suggested individuals with blindness understand spatial information and that Barth (1983), Dick and Kubiak (1997), Quek and McNeill (2006), and Zebehazy and Wilton (2014a; 2014b) suggested SVI process graphical information. Bonnie and Leah expressed that they told their students to focus first on the labels for each axis, and connect the axis information to the function in single steps in order to understand what is going on with the graph as a whole.

With regard to how teachers support SVI in a classroom setting, Bobbi’s mathematics teacher (Kenny) and her paraprofessional (Merriam) assumed different roles, yet they worked together to ensure that Bobbi received adequate assistive technology and instruction to use graphs successfully. Kenny provided verbal cues as he
presented visual content on the board. Merriam read content from the print textbook as Bobbi followed along in the braille version. As Bobbi was doing homework exercises, Merriam asked Bobbi how she was finding the slope and intercept, and which set of coordinates she was using the pins on the board. When Bobbi gave an incorrect response, Merriam would remind Bobbi of the steps she did before, and Bobbi would attempt the correct answer. When Bobbi thought through a step that was incorrect and fixed it, Merriam let her know that she was doing well.

The findings from Chapters 3 and 4 suggest that teachers support SVI with tactile graphics by stressing that their students check the labels on the axes, and understand how the referents connect with the function, in order to understand the layout of a tactile graphic. Chapter 4 provides insight into the type of support one student’s teachers provided in the classroom. However, the degree to which teachers support SVI with graphical information, and the role each teacher assumes in the process, calls for further investigation, as support varies among teachers and needs vary among students.

**Conclusion**

The three papers provide initial information on access, comprehension, and teacher support as facets of education that need to be attended to and improved upon in order to address existing gaps in what is known about the ways in which SVI learn graphical information. A few examples of those gaps center around the influence of the timing and onset of a student’s visual impairment on the ability to comprehend graphs, and the clarity of the roles assumed by teachers serving SVI in the classroom. Future research should investigate avenues for enhancing SVI access and comprehension of
mathematics and science content that is graph intensive so they have opportunities to pursue career paths in mathematics (and STEM, more broadly).
REFERENCES


Brahier, D. J. (2003). Patterns at your fingertips. Teaching Children Mathematics, 9(9), 521-528.


Moon, N. W., Todd, R. L., Morton, D. L., & Ivey, E. (2012). *Accommodating students with disabilities in science, technology, engineering, and mathematics (STEM)*. Atlanta, GA: Center for Assistive Technology and Environmental Access, Georgia Institute of Technology.


APPENDIX A: IRB APPROVAL FOR SURVEY

IOWA STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 4/4/2017

To: Ashley N Nashleenas

1109 Gilman

CC: Dr. Gary D Phye

E006 Lagomarcino Hall

Dr. Anne Foegen

N162D Lagomarcino Hall

From: Office for Responsible Research

Title: Investigating Graph Accessibility and Comprehension of Students with Blindness and Low Vision: Perspectives of Teachers of Students with Visual Impairments and Secondary Mathematics Educators

IRB ID: 17-132

Study Review Date: 4/3/2017

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- You do not need to submit an application for annual continuing review.

- You must carry out the research as described in the IRB application. Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Detailed Information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. Only the IRB or designees may make the determination of exemption, even if you conduct a study in the future that is exactly like this study.

Please be aware that approval from other entities may also be needed. For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.
APPENDIX B: IRB APPROVAL FOR QUALITATIVE STUDY

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Date: 5/5/2017
To: Dr. Ashley N Nashleanas
1109 Gilman
CC: Dr. Gary D Phye
E06 Lagomarcino Hall
Dr. Anne Foegen
N162D Lagomarcino Hall

From: Office for Responsible Research

Title: Investigating Graph Accessibility and Comprehension of Students with Blindness and Low Vision: Perspectives of Teachers of Students with Visual Impairments Through Teacher Perceptions and Student Experiences

IRB ID: 17-169

Approval Date: 5/5/2017  Date for Continuing Review: 5/4/2019
Submission Type: New  Review Type: Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- Use only the approved study materials in your research, including the recruitment materials and informed consent documents that have the IRB approval stamp.
- Retain signed informed consent documents for 3 years after the close of the study, when documented consent is required.
- Obtain IRB approval prior to implementing any changes to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- Immediately inform the IRB of (1) all serious and/or unexpected adverse experiences involving risks to subjects or others; and (2) any other unanticipated problems involving risks to subjects or others.
- Stop all research activity if IRB approval lapses, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- Complete a new continuing review form at least three to four weeks prior to the date for continuing review as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. Approval from other entities may also be needed. For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. IRB approval in no way implies or guarantees that permission from these other entities will be granted.

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.