A STUDY ON INVESTIGATING THE COMMUNITY EXPERIENCES OF TEACHERS OF STUDENTS WITH VISUAL IMPAIRMENTS IN CREATING MATH AND SCIENCE TACTILE GRAPHICS

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DEDICATION

I dedicate this dissertation to my mother Mrs. Woo, my fiancé Sukyung, my family, friends, and Tucson True Light Church's members.

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ABSTRACT

Professional development is essential for certified Teachers of students with Visual Impairments (TVIs) to create high-quality tactile graphics in school settings. The teachers need more opportunities to learn knowledge and skills from other teacher colleagues on a community basis. Few studies were conducted to investigate what community-based interactions are beneficial for professional development in creating tactile graphics. This study investigated the community experiences of TVIs in creating tactile graphics in math and science. Five certified teachers participated in the online community activities and created multiple sets of tactile graphics based on their students' academic needs and subject areas. The researcher facilitated five online community sessions that guided the participants created math and science tactile graphics. Quantitative data were collected using rubric items to investigate changes in self-reported competency and tactile graphic quality. Also, the researcher collected interview data including the participants' reflections about their community experience regarding skill and knowledge development, tool utilization, and participation in a teacher community. This study's findings showed the participants' knowledge and skill development through participating in the activities and improving tactile graphics' quality. The interview analysis found the authentic experiences including awareness of creation procedures, productivity in practice, utilizing tools for planning and evaluation, and knowledge and resource support from other teacher colleagues. Based on the findings of this study, the researcher suggested implications for further research and practice to enrich community interactions of TVIs utilizing online tools and innovative learning models for professional development in creating tactile graphics.

CHAPTER 1: INTRODUCTION

This chapter provides background information about why equitable math and science learning is essential for students with Visual Impairments (VI) who use touch as a primary sense for learning. This chapter will also explain the differences between vision and touch as well as why tactile graphics are important based on equal access to visual information in school settings. The chapter concludes with the study's problem statements, research questions, and conceptual framework in which this study is grounded.

Significance of the Study

Equitable Math and Science Learning for Students with VI

Equitable curriculum access is essential for every learner, whether they have disabilities or not. Students with limited access to learning resources cannot be expected to attain high achievement in learning. Studies have shown a correlation between decreased academic achievement and inadequate accommodations (Krumholtz, 2000; National Federation of the Blind Jernigan Institute, 2006; Thurston, 2014). Visualization is one of the methods most frequently used in classrooms to deliver information. There is an intensive need to offer visual materials in education because 65% of sighted learners depend on vision for learning (Bradford, 2004). At least 75-90% of classroom tasks are vision oriented (Dudovitz et al., 2016; Ripley & Politzer, 2010).

People might think students with VI have inevitable challenges in math and science learning, but the students can be successful when they have access to information. Studies have reported that students with VI are underrepresented in math and science learning compared to sighted peers (Cavenaugh et al., 2006; National Science Foundation, 2002), however, Yeh & McTigue, 2009 found that a lack of accessible materials deprived students with VI of independent learning opportunities, which resulted in lower achievement in math and science. The researchers found that 52.7% of the test items on standardized science tests in 14 states included graphical representations and 79.5% of the graphics provided crucial information for solving the problems. The results showed that interpretation of visual information is essential for competing on standardized tests. However, many students with VI lack adaptations and access to visual information (i.e., pictures, tables, diagrams, and charts) and fewer opportunities to engage in math and science than sighted peers (Martins, 2002; Slough et al., 2010). These findings conclude that vision loss does not lead to an underrepresentation of students with VI in math and science. However, inequitable access to visual information results in loss of learning opportunities and barriers to success in math and science.

Movements to reform science education have been pursued to ensure equitable opportunities and full engagement in science practices for all students from diverse backgrounds, including students with disabilities. Many states in the U.S. have adopted the Next Generation Science Standards (NGSS), highlighting that marginalized learner groups deserve to accomplish science literacy and scientific understanding through instructional shifts to prepare all students to achieve competitive success (Lee et al., 2015). NGSS suggests that students with disabilities deserve an accessible science curriculum and instructions regardless of their disabilities.

Equitable access to science learning for students with diverse needs, including disabilities, has been a focus of interest for several decades. The American Association for the Advancement of Science (1990) published “Science for All Americans,” which reported how science literacy was constructed and what changes were needed to include all students in science learning. The report pointed out that science education practices did not seriously consider the inclusion of diverse groups, including students with disabilities. Aligned with the NGSS’s inclusion goals, the report suggested that math and science engagement allows students with disabilities to understand the nature of science and scientific practices in the real world. Banks et al., 2007) suggested that educators need to be aware of students at risk of unequal opportunities to gain meaningful science learning experiences resulting from personal, socio-economic, and historical factors. The scholars pointed out that educators and policymakers should work proactively to overcome inequity in science education to bridge the achievement gap. Information accessibility provided a rationale for students with VI to have equal opportunities to experience science literacy and classroom practices.

Characteristics of Touch for Learning

Touch as a learning medium has distinct characteristics compared to vision thus special considerations are required when supporting learning of students with VI. First, touch is less efficient and needs more time to process the same amount of information than vision (*Information theory - Physiology*, 2021). Second, students with VI mainly use their index fingers to access information when reading braille and tactile learning resources. Regarding efficiency of information processing, touch can retrieve a limited amount of sensory information while sighted peers process the same amount of information visually. Due to this limitation, teachers need to simplify graphics by selecting only the essential information that the graphics contain when creating tactile graphics (Miller et al., 2010).

Another distinction is that tactile skills need educational support when a learner uses touch for learning. One of the myths is that individuals with VI have a superior tactile sense compared to sighted people. Researchers in neuroscience have investigated how vision loss affects a person’s level of tactile acuity and discrimination (Alary et al., 2009; Van Boven et al., 2000; Wong et al., 2011). The findings indicated that vision loss itself does not enhance tactile spatial acuity, but previous tactile experience functions as a conclusive factor in spatial understanding and discrimination of tactile graphics. The results pointed out that educational support can help students with VI develop tactile skills for learning.

Tactile Graphics in Educational Settings

Tactile graphics are an alternative option that allows students with VI to access visual representations of information by utilizing raised lines and textures. Access to graphic information plays a significant role in successful math and science learning experiences because the subjects require learners to collect, analyze, and interpret data represented using visualization methods. Tactile graphics can support students with VI using touch as a primary learning sense by providing equitable information access as sighted peers use visual learning materials.

Creating tactile graphics does not merely mean converting visual illustrations into embossed tactile information. The work instead involves a process of adaptation to enhance the tactile recognition of students with VI (Jaquiss, 2010). The process requires teachers to spend additional time in school settings and use specialized skills to convert printed material into an alternative format compared to typical visual graphics. This time-consuming process may result in a delay in providing tactile graphics to students with VI. Also, if teachers lack the professional skills to create tactile graphics, students with VI may have challenges fully engaging in the curriculum and learning activities. Furthermore, students with VI need explicit instructions about effectively interpreting tactile graphics converted from visual information. Cognitive access skills include understanding spatial concepts, perceptual processing, and specific cognitive skills to extract meaning from an adapted graphic (Aldrich et al., 2002).

Statement of the Problems

Several issues are still to be resolved regarding creating tactile graphics and providing high-quality tactile graphic skills in educational settings. First, there is a lack of professional development opportunities related to creating tactile graphics. Park and Hong (2022) surveyed 36 TVIs and found they needed more training and resources to create tactile graphics. Some respondents took relevant college courses in their teacher preparation programs as many TVI programs in the U.S. include related knowledge and skills (Rosenblum & Smith, 2012). However, the programs not only have different curriculum but different levels of knowledge and skills, thus additional professional development opportunities are needed to learn creating high-quality tactile graphics through in-service training or continuing education.

Second, there is a lack of collaboration opportunities for TVIs to pursue professional development in creating tactile graphics. TVIs have traditionally relied on workshops and in-service training opportunities for professional development. However, such training has mainly focused on general knowledge and skills in creating and teaching tactile graphics (Park & Hong, 2022; Steele, 2015). The training experiences are not highly relevant to TVIs' specific interests, individual students' academic goals, and tactile skills. Thus, TVIs tend to create and teach tactile graphics individually instead of following formal standards or procedures (Rowell & Ungar, 2003).

Third, students with VI are disadvantaged in assessments and standardized tests due to improper accommodations. The National Center on Educational Outcomes issued a series of reports on state policies on assessment participation and accommodations for students with disabilities (Christensen et al., 2011). The reports found that US states mandated different levels of support in test accommodations. Many states provided limited alternative options for accessing visual information on the tests to evaluate students' academic progress. The reports revealed why students with VI were recognized as an underrepresented group in math and science education and advocated the right to full access to information.

Lastly, existing studies lack relevance to school settings. Researchers in various disciplines have focused on tactile graphics. For example, studies on many types of devices that convert graphic information into tactile forms have demonstrated that the use of devices leads to improvements in tactile acuity and discrimination for individuals with VI across age groups, functional vision, or age at vision loss (Baker et al., 2014; Maucher et al., 2001; Pather, 2014; Petit et al., 2008). The studies focused primarily on technology rather than teaching and learning; thus, further research is needed on developing teaching strategies for tactile graphic interpretation in school settings.

Therefore, this study's findings will provide more knowledge in a TVI learning community for developing professional knowledge and skills in creating tactile graphics by demonstrating the benefits of learning community participation that existing research did not reveal. The community activities in this study will provide a practice-oriented training experience based on collective support with other TVI colleagues, under shared goals of developing knowledge and skills in creating tactile graphics. Also, this study will demonstrate how utilizing different tools for tactile graphics supports creating high-quality tactile graphics supporting each step of creation and revision process.

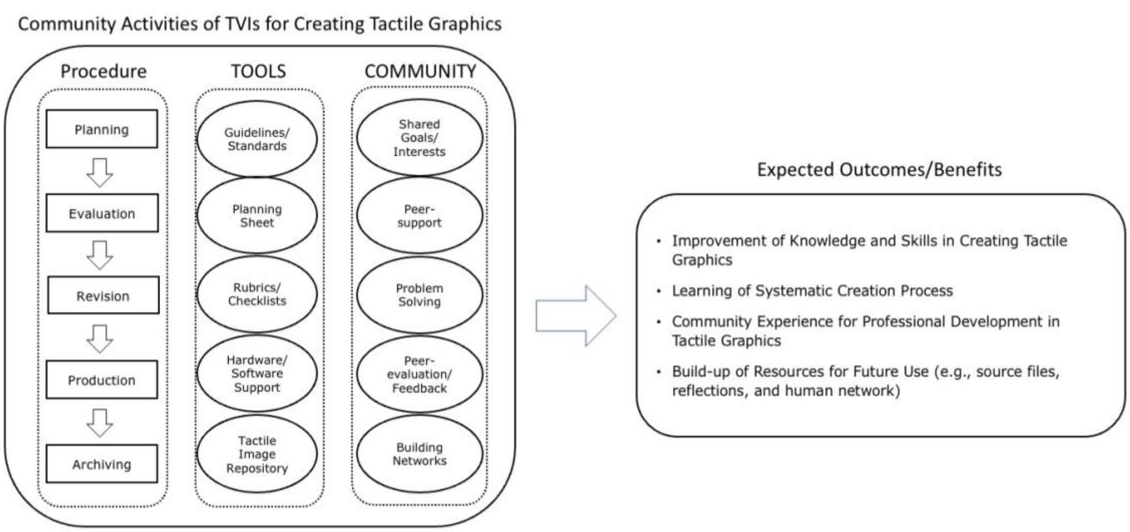
Conceptual Framework

Based on the literature review on tactile graphics and teacher learning community building in education, the researcher developed the conceptual framework of this study to include three strands of support for TVI participants: procedure, tools/resources, and community (see Figure 1). The learning community can be a practice-centered model contributing to improving professional knowledge and skills in creating tactile graphics.

First, the procedure can guide TVI participants to experience a comprehensive workflow for creating high-quality tactile graphics through the steps of planning, evaluation, revision, production, and archiving. Second, participants can utilize relevant resources and tools at each phase of the activities, including guidelines/standards, evaluation rubric, hardware/software support, and tactile image repositories. Third, TVI participants can build a professional learning community under shared goals as working together on decision-making and problem-solving. The community will support TVI participants to improve specific knowledge and skills in creating tactile graphics as well as build human networks and resources.

Figure 1

Graphic Organizer of the Study's Conceptual Framework



Purpose of the Study

This study aimed to explore and analyze the experiences of certified TVIs in participating in a teacher learning community for creating tactile graphics in math and science. One hypothesis that guided this research is that activities of TVIs based on Professional Learning

Communities (PLCs) contribute to knowledge and skill development, utilizing tools, and participation in TVI communities. To answer the research questions, this study collected and analyzed the quantitative ratings of tactile graphic competency and quality evaluation as well as qualitative data to explore TVI participants' experiences through the community activities of creating tactile graphics.

Research Questions

Based on the purpose of this study and the problem statement proposed above, three research questions will be answered through this study as follows:

1. What are TVI's experiences of community activities related to skill development in creation of tactile graphics?
2. What are TVI's experiences of community activities regarding utilizing different tools for creating tactile graphics?
3. What are TVI's experiences in participating in a community when creating tactile graphics?

Definitions of Terms

The following terms are frequently used in this dissertation:

Accommodation: provision of educational services allowing students with disabilities to access the curriculum and demonstrate learning outcomes based on individualized needs in learning.

Professional Learning Community for Teachers: a group of teachers who pursue professional development of expertise in specific areas for teaching as well as meet regularly to share knowledge and works collaboratively for decision-making and problem-solving.

Professional development: continuing learning efforts of teachers and education professionals in a wide range of training, formal and informal education, and professional learning to improve knowledge, skills, and competency for teaching in practice

Tactile graphics: an alternative type of tactile images using raised lines and textures to transform visual representations (e.g., maps, graphs, and charts) for individuals with VI mainly utilize the sense of touch for learning

Teachers of students with Visual Impairments (TVIs): teachers responsible for instructing and providing special education services to meet the exceptional needs of students with VI. These professionals are trained in conducting vision-related assessments as well as planning and evaluating special education programs.

Visual impairments: a partial or total loss of vision encompassing low vision and blindness. The loss causes distinctive characteristics of visual acuity, visual field, contrast, color, or ocular motor function as well as cannot be corrected by medical treatment.

Summary

This chapter has discussed the significance of this study centered on equitable curriculum access and the importance of tactile graphics in educational settings for students with VI. TVIs are responsible for creating tactile graphics and teaching relevant tactile skills in educational settings. Even though previous studies have expanded knowledge for understanding and creating tactile graphics, several issues still need to be resolved through this study. This study provided more understanding on how professional learning community activities supported TVIs' professional development in creating tactile graphics in math and science. Lastly, research questions and definitions of terms are presented. The details of the literature review related to the research questions are described in the next chapter.

CHAPTER 2: LITERATURE REVIEW

This chapter describes the existing literature related to the research questions in this study. This chapter begins by introducing the definition of tactile graphics, the differences between tactile perceptions and vision, and considerations on creating and teaching tactile graphics based on the distinctive characteristics of touch. Also, researchers have described the advantages and challenges of tactile graphics in educational settings that previous studies found. Students with VI can benefit from learning visualized concepts and knowledge delivered through tactile graphics that convey non-visual information in classroom settings. However, classroom teachers and TVIs still have challenges in providing high-quality tactile graphics as well as teaching students with VI the tactile graphic skills needed for proficient interpretation.

Finally, the last two sections describe the roles of TVIs responsible for providing and teaching tactile graphics and the importance of teacher collaboration for professional development. Because TVI communities can provide collective learning experiences and learning interaction, thus the advantages of TVIs ’collaborative effort are discussed in terms of professional development in school settings.

What Are Tactile Graphics?

Tactile graphics are a means of conveying non-textual information that individuals with VI can access through touch. Tactile graphics provide access to visually oriented information, such as diagrams, illustrations, drawings, figures, and charts (Miller et al., 2010). Tactile graphics are not simple reproductions or raised-line versions of the print but rather transformed representations with special considerations of adaptation. Tactile graphics may represent data using symbols and shapes that visualized methods utilize, involving spatial concepts such as borders, directions, and keys that indicate specific elements.

Instead of merely converting a visual illustration by adding textures to printed information, special considerations can ensure easy tactile understanding of actual contents that visual graphics contain (Miller et al., 2010). The Braille Authority of North America (BANA, 2010) defined four primary components that a tactile graphic may include when transformed from a graphical illustration: area, line, point, and label. These components should be considered when creating legible tactile graphics for students with VI.

In addition, TVIs must consider the current tactile perception and recognition skills of students with VI when creating tactile graphics. The professionals are responsible for ensuring students with VI who read tactile graphics can equitably access information for learning as their sighted peers do (Bischop, 2010). The primary consideration is that tactile graphics should extract essential information from a printed graphic and represent its original intent (Miller et al., 2010; Spungin et al., 2007). Features such as colors and viewpoints should also be transformed when the information is essential to understanding visual graphics (Wright, 2008).

Even though many materials and production methods are available for creating tactile graphics, the following methods are most frequently used in school settings: collage, thermoformed vinyl, microcapsule fusers, and computer-assisted braille embossing (Hasty, n.d.). Collage is a tactile graphic using various materials on a flat surface, such as simple fabric and textured paper, glue sticks, and puff paint. The quality of collage graphics may vary depending on the creator's creation and handcraft skills. Thermoformed vinyl is made by heating a plastic sheet and stretching it over a hand-made mold. As the sheet cools, it hardens in the shape of the mold (Tatham, 2003). This method is an affordable option for obtaining endurable tactile graphics that provide three-dimensional (3D) representations of concepts and objects. Microcapsule fusers emboss the inks printed on heat-sensitive paper. A specially designed heating machine processes printed graphics that contain textures. Computer-assisted embossing uses specialized hardware and software to produce embossed lines and textures ranging from braille-dot size to high-resolution dots. Using numerous dots, computer images can be processed and transformed with textures and lines.

Standards and guidelines for tactile graphics support TVIs and tactile graphic product providers. The publications consistently suggest that tactile graphics should present crucial information in a simplified form, just as original visual representations intend to do (Miller et al., 2010). When converting visual information, accidental omission or misrepresentation of information may interfere with understanding the original intent. Thus, the standards and guidelines suggest various techniques for converting printed images into tactile versions.

Above all, simplification and spacing are crucial for determining an easy-to-understand tactile graphic. Simplification is essential for converting visual materials to tactile illustrations (Miller et al., 2010). Printed graphics may contain an excessive amount of visual information. Overabundant details should be eliminated while crucial information is retained. Complicated tactile graphics may result in an unclear understanding of individual components. For example, complex 3D images rendered as two-dimensional (2D) tactile graphics need to be converted into multiple 2D images to avoid confusing viewpoints. In general, BANA recommends that a single tactile graphic item have less than five area textures, line styles, and types of point symbols respectively.

Spacing is also a crucial factor influencing the legibility of a tactile graphic. Multiple elements excessively close in a tactile diagram may provide confusion. Minimum spacing helps avoid the clutter and its reference distance varies depending on the guidelines and standards. For example, the American Printing House for the Blind (APH)’s Tactile Graphics Guidebook recommends maintaining at least 1/8 inch (3mm equivalent) between adjacent elements to eliminate clutter (Amick & Corcoran, 1997). The BANA guidelines recommend at least 1/4 inch (6 mm equivalent), and the Netherlands Library for Audio Books and Braille regulates a minimum of about 1/10 inch (2.5 mm equivalent) to ensure discrimination between two elements (Schuffelen, 2002). These differences depend on produce materials, physical characteristics of elements, textures, and targeted individuals' tactile graphic skills.

Lastly, the quality of all tactile graphic creations must be verified by proofreading using the sense of touch. When visual information is transformed into a tactile graphic, the information should have the same contrast and clarity in graphical form. Proofreading is a process to check whether a tactile graphic transformation successfully conveys crucial information from an original graphic (Schuffelen, 2002). For example, according to the BANA guidelines, all components of tactile graphics should contain discernible textures and not interfere with other components 'identification.

In summary, tactile graphics are recognized as an alternative form of visual information for students with VI. Tactile representations of images should be considered carefully when converting graphics into a tactile format, considering distinctive characteristics of touch. Various skills and techniques are required based on the standards and guidelines' principles. The following section describes the characteristics of touch and related skills for proficient interpretation of tactile graphics.

Characteristics of Tactile Perception

Comparison of Tactile and Visual Perceptions

Tactile perception is different from visual perception. Visual learners mainly process visual information by exploring the "whole to part" (Heller, 2000, p. 8). In other words, visual exploration reveals a complete object; the relationships between minor parts of the object are automatically perceived and multiple viewpoints are easily identifiable once a learner visually explores a whole picture. Visual learners comprehend an image's layout and details by employing scanning skills (Heller, 2000). However, tactile perception sequentially occurs, from "part to whole." Once one part is detectable as the beginning point of physical contact, exploration continues to another part of the object (Heller, 2000, p. 146). The sense of touch processes one part of an object sequentially piece by piece; thus, the whole picture is built by stacking each detail or dimension into an entire totality (Heller & Gentaz, 2013).

Touch can process a limited amount of information compared to vision. Because tactile organs naturally interact with proximal stimuli (Macpherson, 2011), touch may not capture detailed information, while vision processes more details within the same amount of time. Also, depth perception is challenging to the sense of touch because a visual reference point is needed to recognize depth relationships. Complicated graphic items with depth may confuse tactile learners when represented as 2D tactile graphics (e.g., the railroad platform going off in the distance).

There is a myth that people with VI use the sense of touch more efficiently than sighted people. Trained tactile learners show higher proficiency in understanding the environment using touch, and vision loss may serve as one of the factors for tactile discrimination. However, studies showed inconsistent results when comparing the level of tactile perception between groups of people with and without VI. Some studies reported that participants with blindness showed higher perception levels in touch than those with sight (Goldreich & Kanics, 2003; Legge et al., 2008; Norman & Bartholomew, 2011). In other studies, participants with VI exhibited relatively lower performance than sighted participants (Lederman et al., 1990), or no significant differences in the two groups were observed (Alary et al., 2009; Grant et al., 2000). The broad spectrum of results shows that numerous factors, in addition to vision loss, may affect the development of tactile perception, such as tactile skills, previous experience in using tactile graphics, age at vision loss, and inborn cognitive skills.

Tactile acuity and discrimination are the two crucial factors in determining the fluency of tactile graphic reading. Tactile acuity means the extent to which an individual can discern an object's structural details using touch (Binder et al., 2009). Tactile discrimination is differentiating texture information (Kandel et al., 2000). The level of tactile acuity and discrimination may vary depending on various factors, including the use of sensorimotor strategies (Shimizu et al., 1993), and early exposure to tactile graphics (Zebehazy & Wilton, 2014), and enriched tactile experiences (Legge et al., 2008).

Related Skills for Tactile Graphics

When exploring a tactile graphic, various skills are required for understanding and interpreting tactile graphics for learning. First, tactile learners begin to combine the parts by recognizing each component's details sequentially. They consolidate the pieces into a whole assembly by understanding the spatial relationships between multiple elements. According to Miller et al. (2010), students with blindness select a distinctive feature serving as a reference point and identify their fingers' location as they proceed to trace a tactile display. This reference point helps tactile learners locate their index fingers when resuming their exploration once their fingers lose contact and continue to trace. Thus, tactile learners conceive the totality of an object while exploring tactile graphics.

Sequential understanding of spatial relationships results from egocentric sequential processing. Egocentric sequential processing refers to identifying the location of objects centered on the preceptor's body. Because touch can only perceive proximal sensory stimuli, tactile learners focus more on spatial cues close to body parts. According to Miller et al. (2010), egocentric spatial processing may cause difficulties in processing complex spatial information based on visually oriented reference points such as directions (e.g., left and right), distance (e.g., far and distant), and location (e.g., next to, between, and under). Furthermore, rapid changes in viewpoints give individuals with VI more challenges because tactile memories are usually organized from a specific reference viewpoint. Changes in rotation may negatively affect the original spatial orientation.

Based on the characteristics of spatial understanding, students with VI may encounter challenges in recognizing 3D objects represented on a 2D tactile display. Techniques of 3D-to-2D transformation vary depending on the creator's intention or viewpoint on which side of a 3D object is in focus. To understand abstract 3D representations, tactile learners need explicit instructions and early introductions to learning how 3D objects are represented on a flat tactile display (Millar, 2003). Also, a time limit can be a challenge to understanding 3D representations in 2D tactile graphics. As the complexity of 3D representations increases, tactile learners need to take more steps to fully understand each viewpoint and integrate the spatial relationships among components (Heller & Gentaz, 2013). Therefore, simplification is a necessary part of the 3D-to-2D conversion. However, when tactile learners do not have sufficient time or feel overloaded, simplified 2D tactile graphics converted from real objects can be challenging to interpret.

A lack of tactile graphic skills results in lower achievement in math and science for students with VI. (Morash & McKerracher, 2014) studied the performance of students with VI on math problems involving tactile graphics. High-quality tactile graphics were provided for the issues. However, the participants showed a lower level of performance when compared to their same-age peers. The result indicated a need for structured instructions on skills for interpreting tactile graphics for solving math problems.

Previous studies suggested that early exposure to tactile graphics and explicit instructions in tactile skills are conclusive factors affecting proficiency in understanding 3D representations. Empirical results of the studies support the importance of teaching spatial-relationship interpretation. Heller et al. (1996) conducted a study that compared the performance in discrimination of 3D illustrations between two participant groups, one with VI and another with sight. The researchers demonstrated that the group with VI showed a high level of matching viewpoints if the group experienced tactile drawings ahead of time. The prior experiences positively affected their comprehension of multiple viewpoints. In addition, Cattaneo et al. (2008) supported the importance of early exposure to tactile graphics by comparing the level of internalization of a 3D object's multiple viewpoints. They found that the group with blindness simultaneously recalled locations as correctly as sighted participants, resulting in the same performance between the two groups. These results point out that tactile learners can successfully discriminate 3D illustrations similarly to visual learners when students with VI have early experience with multiple viewpoints of 3D representations.

Organizations serving students with VI have specified skills contributing to tactile graphic literacy. The skills are required to interpret tactile graphics in school settings proficiently. The organizations provide specific program goals, including learning activities and resources to develop skills related to tactile graphics. TVIs and caregivers of students with VI should consider introducing basic tactile skills from early childhood when exploring concepts and objects in the real world. Table 1 describes three organizations' lists of skills related to tactile graphics.

Table 1

Summary of the Lists of Tactile Graphic Skills

APH Tactile Skill Matrix (American Printing House for the Blind, n.d.)	PE20: Skills for Tactile Graphics (Positive Eye, 2020)	Iowa Braille School's Tactile Graphics Skills for Math (Iowa Braille School, n.d.)
1. Braille Awareness 2. Creating Graphics 3. Exploration of Real Objects 4. Familiarity with Tactile Graphic Methods 5. Hand Skills 6. Line Tracking 7. Part-Whole Relationships 8. Reading Charts and Tables 9. Reading Graphs and Maps 10. Shape Recognition 11. Spatial and Symbolic Understanding 12. Systematic Scanning 13. Texture Discrimination 14. Transition from 3D to 2D 15. Understanding Perspective 16. Using Keys and Legends	1. Understanding Real Life Concepts 2. Handling Real Objects and Models 3. Two Dimensional Representations 4. Symbolic Representations 5. Tactile Discrimination Skills 6. Fine Motor Skills	1. Motor Skills 2. Tactile Discrimination and Identification 3. Spatial Understanding 4. Interpreting and Creating Tactile Graphics 5. Using Adaptive Tools to Complete Grade Level Problems

Advantages and Challenges of Tactile Graphics in Educational Settings

Benefits of Tactile Graphics in Math and Science

The use of tactile graphics is beneficial for students with VI. Researchers have studied how tactile graphics affect math and science achievement, relevant skills, and students' learning needs related to VI. (Rule, 2011) reported that a planetary science program's tactile graphics provided participants with a positive attitude and understanding of content knowledge. She conducted a practice study using a short-term astronomy camp to investigate the effectiveness of incorporating tactile materials into the course curriculum for students with VI. The participants received science tactile materials, such as contour maps, models of craters, asteroids, and topographic features of Mars. The pre-and-post test results revealed that the adapted program increased positive attitudes toward science learning and concepts with improved learning engagement. This study supports the notion that students with VI can succeed in the general science curriculum if provided with accessible and specially designed learning materials.

Rule (2011) subsequently examined how adapted materials affected classroom teachers' awareness regarding the provision of adaptive materials and resource supply. The researchers examined attitude and instructional changes in 15 math and science teachers educating students with VI throughout one year of the program. The use of adapted tactile learning materials for students with VI led to an increase in general education teachers' awareness and positive attitudes toward providing supplemental adaptive materials, supplies, and equipment. Positive changes were noted from pretest to posttest in student and teacher perspectives as well as teacher attitudes towards students with disabilities in STEM classes.

Landau et al., (2003) examined the effectiveness of the Talking Tactile Tablet, a device to display tactile information using textured lines and images for reading figures and tables. The device allows students with VI to tactually access graphical elements for multiple-choice math tests with additional audio descriptions of each tactile image. The participants showed more improvement on the math test items when using the device than without the tactile aids.

Challenges to Creating and Teaching Tactile Graphics

Despite the advantages, many challenges were found when creating and using tactile graphics in school settings. Tactile graphic creation requires intensive time and labor commitments, thus resources may not be available when students need them (Allman & Lewis, 2014). Zebehazy and Wilton (2014) examined TVIs' perceptions and practices regarding tactile and print graphics produced for students with VI. The researchers used an electronic survey to investigate how the TVIs perceived the graphics' quality and importance and how they taught tactile graphic skills. The participants agreed that tactile graphics were essential for learning and assessment. However, state and regional evaluation tests did not allow full access to graphics adaptations. Another challenge was that TVIs could not commit sufficient time to teach specific skills for reading tactile graphics. Early exposure to tactile graphics was recognized as a determining factor in the tactile skills of students with VI; however, too few instruction hours resulted in a lack of opportunities to provide explicit instructions on using tactile skills. Further, the TVI participants pointed out that they didn't have enough time to plan and create tactile graphics. Their excessive workload prevented TVIs from committing sufficient time to creating high-quality tactile graphics following guidelines and standards.

Students with VI experience challenges in using low-quality tactile graphics when learning academic content in the classroom. Rosenblum and Herzberg (2015) conducted interviews with students with VI to investigate their school experiences. Many tactile graphics that the students received lacked vital information that visual graphics contained and even contained errors. For example, the students sometimes could not find chart grids, embossed numbers on axes, or textured lines. These challenges discouraged students with VI from using tactile graphics in academic learning.

In addition, students with VI who use tactile graphics for academic learning may lack necessary tactile and cognitive skills. Aldrich and Sheppard (2001) investigated the perspectives of students on their tactile graphic experiences. The researchers found that students with VI had concerns regarding interpreting abstract tactile graphic images. The students sometimes struggled to understand the information described through tactile graphics that lacked distinct textures, sizes, labels, and colors. Based on the results, the researcher suggested individualized instruction on tactile skills to improve students' interpretation of tactile graphics.

Lastly, the low technological proficiency of TVIs is a noticeable challenge to providing high-quality tactile graphics. Computer-assisted methods have been recognized as essential tools for creating tactile graphics, so computer proficiency is required for TVIs when creating high-quality tactile graphics. Zhou et al. (2012) conducted a national survey on TVIs' assistive technological competencies. The results showed that TVI participants self-evaluated their competencies as low, especially in handling software and hardware related to creating tactile graphics, indicating that they required additional training and resources. This finding aligns with a study reporting that TVIs lacked confidence in creating computer-assisted graphics (Park & Hong, 2022). Technology readiness is directly related to creating high-quality computer-assisted tactile graphics. The study's results demonstrated that more professional development on handling hardware and software related to computer-assisted tactile graphics is demanded.

Tactile Graphics for Universal Design for Learning (UDL)

Since visualization is the most frequently used method to present information, vision loss cause challenges to ensuring equitable learning in classroom settings. Tactile graphics provide non-visual alternatives to visual representations of information to eliminate barriers to information. Students with VI use tactile graphics with texture equivalents that convey critical concepts just as sighted students use visual information to understand information for learning. Depending on individual learning needs, tactile graphics are one of several options to access information, including other non-visual alternatives such as audio descriptions and physical objects.

Universal Design for Learning (UDL) is an alternative consideration for ensuring an inclusive environment for all students with diverse learning needs including disabilities, and it is grounded in the premise that all curricula must be easily accessible by students with various learning styles, languages, and abilities (Rose & Meyer, 2002). For students with disabilities, UDL principles provide a new perspective on designing a more flexible curriculum that will be effective for all students' diverse learning needs, emphasizing the need to begin the design process with accessibility in mind instead of modifying the curriculum later to meet individual students' needs. In a traditional setting, the label "disability" or "underachievement" is attached to individuals who fail in a curriculum, resulting in efforts to "fix" students (CAST, 2018).

The UDL approach focuses on the disability of the curriculum because it is the curriculum itself that does not meet all students' learning needs; thus, the curriculum needs to be fixed. Aligned with these principles, UDL should not serve as an ideology or an educational paradigm but as support for generating meaningful positive outcomes in educational settings. UDL is also necessary to help students with diverse needs and abilities fully complete the general education curriculum by eliminating the barriers students face in educational settings. To achieve the goals, (Hitchcock et al., 2002) proposed the three principles of UDL as follows:

(1) Provide multiple means of representation to support cognitive learning. This refers to providing a flexible way to represent what is taught and learned.

(2) Provide multiple means of action and expression to support strategic learning. This refers to providing options regarding how students learn and express what they know.

(3) Provide multiple means of engagement to support the effective aspects of learning. This concerns the "why" of learning and refers to providing options to motivate students.

Among the three principles, providing multiple means of representation is particularly important for making materials and information accessible for students with VI. The principle refers to various ways of delivering learning content. Diverse representations of information are essential because learners make connections to the "what" of learning differently (Rose & Meyer, 2002). A single representation of information is not appropriate for all students, who have various ways to understand information. For example, students with VI using touch as their primary sense cannot access printed learning materials and graphics in classrooms. Every curriculum under UDL principles has various representation methods. Students with VI approach learning content such as tactile graphics, enlargement options, audio descriptions, and multimedia options to access information as sighted peers do.

Table 2

Checkpoint Details of UDL Guideline 1

Principle 1. Provide Multiple Means of Representation
Guideline 1: Provide options for perception Checkpoint 1.1 - Offer ways of customizing the display of information Checkpoint 1.2 - Offer alternatives for auditory information Checkpoint 1.3 - Offer alternatives for visual information

Following Guideline 1, tactile graphics are customizable alternatives for visual information, meeting Checkpoint 1.3. UDL supports providing students with VI with multiple alternatives to vision-centered information. Checkpoint 1.3 provides fundamentals for equitable access to information for learners with VI using other learning media instead of vision. Tactile graphics can be combined with multiple other non-visual equivalents to support equitable curriculum access when tactile-only modality limits understanding of graphical information. Multiple modalities help tactile learners explore graphics effectively. For example, written or audio descriptions support students with VI by providing access to crucial information that tactile graphics might not cover. The combination establishes a UDL-based instruction and curriculum for students with VI by offering multiple options equivalent to visual information.

In summary, UDL can provide fundamental principles for developing teaching practices that provide students with VI equitable access to the curriculum. Among non-visual alternatives, tactile graphics have been recognized as an effective way to provide students with VI equivalent to the visual information their sighted peers utilize. Based on UDL principles, TVIs should consider the individual knowledge and tactile skills of students with VI when providing non-visual equivalents.

Roles of TVIs Related to Tactile Graphics

Professional Standards Related to Tactile Graphics Provision

Professional organizations serving TVIs and students with VI provide quality standards for TVIs, which contain items related to professional knowledge and skills in tactile graphics. Because creating high-quality tactile graphics and teaching tactile skills are standards, TVIs need to be professionally trained in their career paths (Bischop, 2010; Spungin et al., 2007). For example, the Council for Exceptional Children (CEC) developed a series of skills to implement evidence-based educational practices for students with disabilities. The CEC's Division on Visual Impairment and Deafblindness developed a skillset titled "Initial Specialty Set" for supporting the learning needs of students with VI (Council for Exceptional Children Division on Visual Impairments and Deafblindness, 2018). As the CEC standards include "select, adapt, and use instructional strategies and materials" based on the exceptional learning needs of students with disabilities, the division standards consist of the following professional skills for creating and teaching tactile graphics:

BVI.5.S3 Use digital resources, hardware, and software to produce and access materials in accessible media including the conversion of print materials into braille, tactile, and/or digital formats.

BVI.5.S9 Teach the use of the abacus, accessible calculator, tactile graphics, adapted equipment, and appropriate technology for mathematics and science instruction to meet individual needs.

BVI.5.S10 Teach students to access, interpret, and create increasingly complex printed and digital graphics in visual and/or tactile forms, including maps, charts, diagrams, and tables, based on individual needs

BVI.5.S11 Teach students with low vision to use optical, electronic, and non-optical devices to optimize visual efficiency and independently use dual learning media such as visual and auditory information, or auditory and tactile information

These items also serve to evaluate college and university vision programs and plan continuing education programs. The skillsets function as quality indicators to maintain the programs 'performance by evaluating the curriculum. The standards ensure that TVIs can demonstrate skills associated with tactile graphics in the field, and college/university TVI-preparation programs need to consider these skills when designing and improving their curricula. Upon initial licensure and through continuing professional development, TVIs need training in the knowledge and skills for creating and teaching tactile graphics as well as converting printed or digital materials into tactile formats.

When TVIs create tactile graphics, the conversion highly relies on the teachers ' considerations and planning. The human factor may affect determining if the converted graphic is usable for students with VI. Smith and Smothers (2012) examined that even tactile graphics in textbooks had discrepancies to their original graphics showing omission of information, errors, and different descriptions. Herzberg and Rosenblum (2014) also found an inconsistency in professional-created tactile graphics for students with VI, such as braille errors and variability of labels in math worksheets. These findings pointed out that ensuring essential components determine the quality of tactile graphics created by TVIs in school settings. Not considering the components may result in errors while converting from the original graphics. The quality of tactile graphics relies on how they are prepared with consideration of essential components.

Assessment and Instruction of Tactile Graphic Skills

In addition to creating tactile graphics, TVIs are mainly responsible for evaluating current tactile skills and determining the goals of tactile graphic skills. Schools and agencies serving students with VI have provided assessment tools and resources related to tactile graphics. The Texas School for the Blind and Visually Impaired (TSBVI, n.d.) developed an assessment tool to evaluate the grade level of tactile graphic skills. The assessment tool is designed to evaluate the following five skill areas: motor skills, tactile discrimination/identification, spatial concepts, interpretation and creation of tactile graphics, and skills to solve grade-level problems. TVIs can use the tool to determine students' present level of performance and evaluate progress and achievement of tactile graphic skill goals.

Also, APH developed the "Tactile Skills Matrix," which contains tactile skills and concepts matched with the APH commercial products for developing tactile skills and concepts (American Printing House for the Blind, n.d.). The matrix proposed a series of skills and concepts to support the development of tactile graphics interpretation, including physical and cognitive skills. This online tool helps TVIs to locate commercial products that contribute to developing skills for tactile graphic literacy.

Based on the determination of current tactile graphic skills, TVIs need to provide explicit instructions that meet the learning needs of students with VI. APH's Tactile Graphics Guidebook (1988) initially suggested a framework for introducing tactile map reading as highlighting the importance of preliminary skills in understanding spatiality and environment orientation before understanding tactile graphics. For example, tactile map reading needs a combination of cognitive work and orientation to the environment. The first step is to teach basic spatial/location concepts and spatial relationships. Tactile learners are expected to learn to examine a tactile display's totality by tracing the whole picture using both hands. While identifying the display's size and perimeter, both hands employ a series of systemic scans from top to bottom and left to right. Tactile learners continue the scanning process by tracing specific lines or areas in the display, thus recognizing the tactile representation's totality. The use of fingers affects tactile map reading. Lead fingers, usually index fingers, determine the direction of tracing. The other fingers are responsible for following behind and serving as a reference. If a tactile reader gets lost, lead fingers will return to the reference fingers and then continue. The instruction framework is aligned with the hierarchy of tactile skills described by the assessment tool and the tactile skill matrix, ranging from understanding the physical environment to interpreting tactile maps as abstract forms of the real world.

Professional Learning Community for TVIs

This study was informed by the approach of PLCs that benefit professional development and students' learning success. PLCs provide opportunities for teachers to work with others under shared goals and vision of teaching practice. They regularly meet and share resources, strategies, and experiences in specific areas of knowledge and teaching practice (Stoll et al. 2006). PLCs refer to a group of teachers pursuing professional development through collaborative learning activities. The community is oriented toward sustainable groups of teachers establishing a learning culture under shared goals, values, and mutual interdependence (Leonard & Leonard, 2001). PLCs enrich sharing best ideas and resources for best practice with other teachers as well as create a new body of knowledge together when interacting in a community. The community functions as a venue where "educators committed to working collaboratively in ongoing processes of collective inquiry and action research to achieve better results for the students they serve" (DuFour et al., 2006, p. 217). The approach is grounded on socio-cultural learning perspectives, meaning meaningful interactions and relationships considerably influence professional development.

Teacher's PLCs are essential as it encourages teachers to pursue ongoing professional development and innovative teaching practices, fostering high-quality education. Garmston & Wellman (2016) asserted the importance of teacher communities to enhance the quality of teaching and learning outcomes. Through participating in PLCs, members of teacher communities aim to solve potential common problems caused in schools where they are involved. Teacher communities can provide a positive force to help individuals pursue professional development for innovative teaching practices. Sigurðardóttir (2010) highlighted the following characteristics of PLCs:

- Shared values and vision that focus on students' learning.
- Shared leadership that values teachers' participation in making decisions.
- Collaborative learning among professional staff that addresses members' needs.
- Organizational arrangement that supports teachers' collaboration.
- Habits of work that encourage collaborative learning.
- A social climate that supports collaborative learning.

Collective accountability and learning for professional development consistently encourage teachers to pursue continuing professional development and innovative teaching practices. In school settings, researchers reported that collaboration allows individual teachers to maintain high motivation and consistent interest in professional development through collective work, including decision-making and problem-solving (Bullough & Gitlin, 2001; Knight et al., 2000). The studies demonstrated that a high level of teacher collaboration led to professional development that supported better learning practices. In addition, Garmston & Wellman (2016) asserted that teacher communities enhance the quality of teaching and students 'learning outcomes. Teachers participating in teaching communities are more likely to pursue professional development in innovative teaching practices. Several empirical studies have shown that collaboration among teachers resulted in higher levels of professional development across various school settings (Arter & McTighe, 2001; Garmston, 2007). The studies also found that professional development supported better learning practices.

Collective professional development experiences through building PLCs can potentially improve the quality of teachers 'instruction by expanding their knowledge and introducing effective teaching practices. Larson et al. (2012) suggested a model of grade-level communities to improve math teachers ’understanding of the curriculum, knowledge of instruction, and assessment skills. The community building supported the teachers to share creativity and relevant math practices as working together to develop viable lessons and assessments in school settings. In addition, teachers could utilize collectively developed high-quality assessment resources. These efforts helped avoid isolation by individual commitments and pursue continuous learning to build knowledge and skills in teaching.

After the outbreak of the COVID-19 pandemic, the potential of online PLC was recognized as a fundamental approach for teachers’ professional development. Initially, Ford et al. (2008) used the term “virtual PLCs” to describe various asynchronous and synchronous tools, including teleconferencing, electronic discussion groups, and course management software. These tools intend to utilize technology to overcome geographic barriers and disconnections of teachers. To enrich effective online PLCs, the components are essential such as 1) skilled facilitators, 2) availability of collaborative online tools, and 3) stable and user-friendly platforms (Fulton & Britton, 2011). TVIs recognized more importance of online learning communities for professional development. In-person collaboration and interactions between teachers rapidly transitioned to the online environment using teleconferencing. TVIs faced challenges in delivering special education services to students and collaborating with colleagues due to challenges to physical access to people and school facilities (Rosenblum et al., 2020). The professional development opportunities were also delayed or only allowed fully online to mitigate health issues and maintain social distancing.

Collaborative efforts for best practice are recognized as one of the most crucial forms of professional expertise for TVIs in school settings. TVIs are responsible for communicating with educational and multidisciplinary professionals; thus, collaboration skills are essential for implementing quality interventions and instructions. Studies found that collaboration models affected the provision of high-quality teaching and programs that specialized in the individual educational needs of students with VI (Erin, 2015; Pogrund, 2017).

Collective learning between TVIs has been considered a powerful method for professional development in creating and teaching tactile graphics. Council for Exceptional Children’s Division on Visual Impairments and Deafblindness developed a set of standards that TVIs should master upon initial licensure and in continuing professional development. The standards specified the importance of collaboration for building knowledge and skills, stating that TVIs need to collaborate with TVI colleagues and other professionals to ensure a high-quality and equitable learning environment for students with VI. Regarding tactile graphics, BANA highlighted that professionals, including TVIs and braille transcribers, should collaborate to maintain a consistent quality of tactile graphics. Consistency of planning and formatting ensures tactile graphics' quality and prevents confusion when students with VI use various tactile graphics. Based on the literature, researchers concluded that collaboration helps TVIs develop professional skills in creating and teaching tactile graphics.

The collaboration-oriented practice has a high potential for TVIs to pursue professional knowledge and skills in creating tactile graphics. According to Zhou et al. (2012)’s national study, TVIs perceived collaboration skills as a strength among various TVI competencies in school settings. In contrast, their perceptions of knowledge and skills for creating tactile graphics were relatively low. Across different educational backgrounds, TVIs are employing collaboration skills in their practices. Researchers have reported positive impacts on the educational success of students with VI resulting from collaborations among service providers, such as a school for the blind and local education agencies (Zebehazy & Whitten, 2003); a TVI, and a physical therapist (Stearns, 2017); educators and transition associates (Brown et al., 2013); and TVIs and rehabilitation service providers (Brown et al., 2013). The results showed that TVIs' knowledge and readiness for collaboration in a professional community have the potential for professional development in learning knowledge and skills related to supporting the education of students with VI, especially in creating tactile graphics.

PLCs for TVIs have the potential to connect to colleagues providing professional development opportunities with specific areas of interest for supporting students with VI in school settings. As of 2021, almost 89.6 percent of students with VI in the U.S. receive special education services in general education (U.S. Department of Education et al., 2022), so many TVIs serve the students within a school district as itinerant teachers. TVIs need various forms of in-service training to foster successful inclusion and teach students with VI based on evidence-based teaching (Gewinn et al., 2021). According to Correa-Torres and Howell (2004), itinerant TVIs are concerned with an overwhelming workload and training needs in knowledge and skills that they were not trained in college and university TVI programs. Combatting isolation and lack of professional development opportunities negatively affected being highly qualified.

To overcome the challenges, online-based PLCs have the potential to easily access, connect to professional colleagues, and pursue collective learning with other teachers with shared goals in specific teaching. The communities can support teachers to retain particular knowledge and skill in teaching as well as social support (Lin et al., 2016) based on socially situated learning of professional expertise in specific areas related to learning and teaching, which is based on social theories of learning (Booth & Kellogg, 2015; Wenger, 2010).

Researchers have suggested the benefits of community-based professional development. Based on shared interests in specific areas, the communities can promote mutual commitment to demonstrating meaningful learning outcomes resulting from engagement and interactions between collective learning processes. For example, Pogrund (2019) introduced a group of professionals interested in teaching students with severe multiple disabilities using teleconferencing tools. The group supported sharing strategies and collectively resolving the challenges in practice based on reciprocal learning between colleagues. In addition, Siu and Morash (2014) developed a measurement tool and applied it to evaluating TVIs' technology proficiency depending on the identification of PLCs with shared values in assistive technology. They revealed that the TVI participants who scored high in the proficiency items showed a high level of community identification. These study findings supported the positive impacts of teacher communities on TVIs 'professional development leading to knowledge and skill development in teaching practice.

Based on the review of literature review, this study focused on exploring how online-based PLC activities influenced the professional development of TVIs in creating math and science tactile graphics in school settings. Because creating and providing quality tactile graphics are recognized as expertise of TVIs who serve students with VI in school settings. Continuing professional development is demanding in various formats. The online PLC activities provided collaborative learning opportunities based on shared interests, and goals and focus on student success.

Summary

This chapter addresses existing knowledge and studies on tactile graphics and educational practices grounded in this study. The sense of touch has distinctive characteristics for perception and interpretation than vision, so TVIs should carefully consider the differences when teaching specialized skills for academic learning in school settings.

Tactile graphics can be an alternative option to provide accessible information for equitable curriculum access in math and science. Tactile graphics must be simplified and yet retain the crucial information that original visual graphics represent. Several standards and guidelines for tactile graphics provide considerations and recommendations for creating tactile graphics. Also, professional standards specify that TVIs are responsible for creating legible tactile graphics to support the curriculum access of students with VI. The specifications ensure that TVIs need to pursue professional expertise related to creating and teaching tactile graphics upon licensure and continuing education.

Professional communities of teachers have been used for teachers 'professional development in the educational field. Existing studies have proved that teachers' collective work and communication positively impacted building knowledge and skills related to instruction and motivation to continue pursuing professional development. In the next chapter, the details on intervention activities and data collection/analysis will be addressed to answer the research questions in this study.

CHAPTER 3: METHODS

This study collected and analyzed both quantitative and qualitative data from TVIs throughout the community activities to answer the research questions. Throughout the activities, the researcher collected quantitative scores of participants' self-reported competency and peer-evaluations of quality as well as qualitative interview data by facilitating four virtual interview sessions. This chapter includes the recruitment procedure, participant demographics, activities overview, qualitative/quantitative data collection and analysis, and a summary.

Participant Recruitment Procedure

The Institutional Review Board of the University of Arizona (UA) approved this study. The researcher recruited participants who met the following eligibility criteria: 1) teaching in a school for the blind or working as an itinerant teacher with students with VI, 2) having at least one middle or high school student with VI who used the sense of touch as a primary learning medium and needed tactile graphics for math or science learning, and 3) being available for this study and able to engage through virtual meetings and email. The researcher sent the recruitment flyer (see Appendix A) to email listservs and posted it on TVI social media group. The study flyer was also sent to local TVIs, administrators, and other Arizona stakeholders. The researcher scheduled online meetings with potential TVI participants and provided additional information, including an overview of the study, the expected timeline, and eligibility criteria for participation.

Five teachers who met the eligibility criteria signed the consent form (see Appendix B). Also, the participants were asked to answer survey questions on demographic information (see Appendix C), self-reported competency in creating tactile graphics, tactile graphic needs of their students in math and science, and preferred telecommunication methods. Before facilitating the first meeting, the researcher gave an overview of the study, outlining the activities and agenda for each session. There was no monetary compensation for participants related to this study, however, the participants who completed the activities according to the consent form received a $100 merchant gift card funded by the Research and Project Grant of the UA's Graduate and Professional Student Council.

Participant Demographics

The five participants had diverse backgrounds of teaching settings and interests in tactile graphics. Three participants worked in specialized schools in Arizona, and the others were itinerants in Delaware and Pennsylvania. The participants had middle or high school students with VI who needed tactile graphics for academic learning. Based on the eligibility criteria, the participants decided to select up to two areas in math or science. The math areas consisted of geometry and data interpretation, and science areas including biology, chemistry, and physics. Also, two participants had previous training in tactile graphics, whereas the other three did not. The following is a description of each participant. Note that all names are pseudonyms.

Tiffany

Tiffany was a 57-year-old White female itinerant TVI working at a public school district in Delaware. She has been working as a TVI since 2017 and taught students with disabilities before starting in the TVI position. She learned to create tactile graphics by collaborating with colleagues and experienced senior teachers. At the time of the study, she supported 7th-grade students with VI by preparing accessible learning materials and teaching VI-specific areas, including braille. Her areas of interest were creating tactile graphics to support her students to measure circles in math, learn the structure of cells, understand the properties of matter, and learn the basics of genetics. Her expectations for this study were mainly to collaborate and receive feedback from other TVI colleagues. She preferred manual creation methods because her tactile graphics were usually created on the fly within a limited time. Her creation method was to convert the original graphic by giving textures using various materials. Her average self-reported competency score was 3.92 out of five, ranging between “good” and “very good.” She was confident in her ability to create tactile graphics but rated a relatively low on the item "simplification and elimination of information” compared to the others.

Shawn

Shawn was a 30-year-old White male who had worked as a TVI at a non-profit education agency for students with VI in Arizona for the last five years. Before starting a TVI career, he worked as an alternative format specialist at his university’s Disability Resources Center which supported college students with VI for four years. Through those experiences, he learned to create braille, electronic texts, and tactile graphics according to his university’s protocols. He taught himself details and rules for creating tactile graphics. His interest was making tactile representations of multiple parts of an animal cell for middle school students. He was experienced in utilizing a computer-assisted braille translator as well as using the EZ-Form Brailon Duplicator, a machine to reproduce braille and make tactile copies (*EZ thermoform machine (110V),* n.d). His self-reported competence score was 3.42 out of five, between “good" and “very good.” He was confident with simplifying and eliminating information, using computer-assisted methods, and ensuring tactile clarity, whereas he rated using a checklist relatively lower than the items.

Perry

Perry was a 57-year-old White female itinerant TVI working with high school students in Pennsylvania. She had worked as a TVI for the previous six years and had worked as a material specialist and a paraprofessional before receiving her TVI certification. She was confident in brailing and utilizing computer-assisted hardware and software for creating tactile graphics, based on her material specialist experience. She was interested in tactile graphics for high-school-level geometry topics such as intersecting lines on four quadrants and triangle congruence. She was interested in learning different creation techniques and sharing resources with TVI colleagues. Her average self-reported competency score was 3.75 out of five, ranging from “good" to "very good.” She was not only aware of the guidelines and standards but had experience in reviewing newly produced commercial tactile learning materials. She was familiar with several tactile image repositories due to her long years of teaching experience.

Kiley

Kiley was a 34-year-old White American female teacher in a school for the blind in Arizona. She had been teaching students with VI for the previous five years. She learned to create tactile graphics in the TVI program courses and wanted an in-service learning experience in creating tactile graphics. Her areas of interest were teaching independent living skills with combinations of data representations in math. To compare quantities and numbers, she wanted to create interactive tactile bar and line graphs her students could use to record and interpret data, such as reading and writing assignment scores. Her average competency score was 2.83 out of five, ranging between “fair” and “good.” She stated that her strengths were ensuring tactile clarity and following guidelines and standards, whereas she reported her competency as relatively low on the items of simplification and sizing. Also, she was not confident in utilizing hardware and software for tactile graphics, thus preferring to use manual creation methods for her drafts.

Kamila

Kamila was a 35-year-old Chinese female science teacher in a school for the blind in Arizona. She worked as a life skills teacher and worked with students with cognitive disabilities and autism before teaching as a TVI. At the time of the study, she taught science to middle school students with VI and thus decided to create tactile graphics presenting different basic physics principles. In her TVI program, she learned to create tactile graphics using Picture-In-A-Flash (PIAF) machine to support an out-of-school science program for students with VI in her city. She mostly learned to convert printed materials into tactile graphics from her colleagues in her school. She was interested in creating tactile diagrams that represented numerical vector values of force in specific directions. Her average self-reported competency score was 1.58 out of five, ranging between “poor” and “fair.” She considered herself a “newbie” TVI who had started recently and was looking forward to a learning experience in creating tactile graphics.

Professional Learning Community Activities Overview

The researcher facilitated five online learning community sessions in which participants created math and science tactile graphics. If participants missed the regular meetings due to personal or health issues, the researcher scheduled one-on-one meetings to catch up and continue engaging in the community interactions. At the first meeting, the participants began by introducing themselves and sharing their interests in creating tactile graphics related to their student's math and science goals. After deciding on individual subject/content areas for conversion, the participants shared their previous creation experiences, current knowledge and skills, and thoughts on creation methods, including hardware/software.

In the next meeting, the researcher facilitated using BANA’s Tactile Graphics Decision Tree (see Appendix E). This tool aimed to guide the participants in determining if their original graphics were eligible to be converted into tactile graphics based on the following three criteria: 1) the graphic was repetitive of facts in the text, 2) it was meaningful when transcribed in text, and 3) students needed the graphic to complete an academic task in class. If a graphic did not meet one of the three criteria, the participant was asked to replace it with another that would be a better fit for tactile graphic conversion.

The participants brainstormed what visual information should be simplified into a tactile graphic. The researcher introduced several examples of quality conversions in math and science with a checklist to ensure tactile readability. Using the checklist, the participants discussed their planned tactile graphic conversion process, including simplifying, decluttering, limiting the number of patterns, and ensuring correspondence to the original visual graphics, then completed BANA's Tactile Graphic Planning Sheet (see Appendix F) that specified the information to be presented and the specific illustrations to be simplified to ensure easy tactile perception and differentiation.

The planning sheet was intended to support the participants for systemically converting a visual graphic into a tactile form with consideration of 1) simplification, 2) size adjustment, 3) elimination of superfluous information, 4) tactile clarity and spacing, 5) textures and patterns, and 6) keys, symbols, and numbers. The participants were asked to complete individual planning sheets for each tactile graphic. The participants' creation methods ranged from low-technology methods using manual techniques to high-tech computerized design tools such as Quicktac, a braille-based tactile graphic drawing tool.

Throughout the fourth meeting day, the researcher facilitated sharing each participant's drafts tactile graphics and then discussed specific considerations on the planning sheets. At the end of the introduction, the group shared feedback and comments for improvements, which expanded participants' knowledge of potential creation ideas and methods. Then the researcher introduced the evaluation rubric (see Appendix G) with the purpose of the rubric and its evaluation items with quantitative ratings and written response feedback. During the next two weeks after the meeting, the participants were asked to complete evaluations of their own drafts as well as those of two colleagues. The quantitative scores and qualitative written-response feedback were collected using an electronic form.

At the last meeting, the participants shared ideas on revision for ready-to-go versions of their tactile graphics and an implementation plan for utilizing the final versions in teaching. Some qualitative comments were reviewed and clarified during the meeting through talking with the other participant evaluators. The participants then confirmed their expected progress in revising the drafts. Also, the post-scores of self-rated competencies were collected at the end of the meeting. The summary of community activities and data collection tools that the researcher utilized through the activities. The summary of activities conducted throughout this study is itemized in Table 3.

Table 3

Itemized Summary of Activities (Day 1-5)

	Activities	Implementation Tool(s)
Day 1	• Introduced each other. • Shared interests/experiences related to creating/teaching tactile graphics. • Decided subject/content areas based on students' math and science goals. • Shared a collection of resources.	• Demographic survey form (Appendix C) • Self-reported competency evaluation form (pre-test, Appendix D)
Day 2	• Shared individual participants' original graphics.	• BANA's Tactile Graphics Decision Tree (Appendix E)

	• Determined if original graphic(s) are appropriated for creating tactile graphics.	
Day 3	• Learned the items for considerations in the checklist and planning sheet. • Brainstormed ideas for converting original graphics to tactile graphics.	• Tactile Graphic Checklist • BANA's Tactile Graphic Planning Sheet (Appendix F)
Day 4	• Learned to use the quality evaluation rubric. • Provided peers with written feedback for revisions.	• Tactile graphic quality evaluation sheet (Appendix G)
Day 5	• Introduced the details of revisions. • Archived tactile graphics and shared resources. • Reflected learning outcomes of participation. • Scheduled for interview sessions.	• Participants' final tactile graphic products • Self-reported competency survey (post-test) • Interview guiding questions (Appendix H)

Between the regular online meetings, time was devoted to using asynchronous electronic discussions and secured cloud storage to share the creation procedure's progress. The culminating goal for the discussions was to develop the knowledge and skills of the participants in creating tactile graphics. Thus, the asynchronous discussions were intended to enrich community interactions between the participants as well as reflections on their learning curves specific to creating quality tactile graphics. The participants focused on providing regularly productive feedback per each creation procedure throughout the planning and revising tactile graphic drafts ensued. The researcher facilitated collectively solving problems that they could face during the creation procedure. Through the asynchronous discussions, the participants could offer comments that included resources and diverse ways of simplification and adaptation. For example, after the second meeting, each participant drafted two planning sheets and provided other participants with feedback for improvements. Others sometimes would ask for more information about resources. The planning sheets were stored and shared in a secured cloud folder where their colleagues could explore other participants' outcomes and progress. After the asynchronous community interactions, the researcher's follow-up discussions were facilitated based on the asynchronous interactions.

Quantitative Data Collection/Analysis

Self-reported Competence Evaluation

The researcher the two sets of self-reported competency ratings related to knowledge and skills in creating tactile graphics before and after the community activities (see Appendix D). The evaluation sheet was created using a free online survey tool to collect their scores electronically. The ratings consisted of 12 question items using a 5-point Likert scale ranging from “Very good” to “Never tried.” The researcher set the items as an ordinal scale with “Never tried” representing the lowest value (score 1) and “Very good” representing the highest value (score 4) because the distances between each scale were not measurable but the order of competency items was clear and possible to rank (Norman, 2010). The researcher did not include the numeric in the competency ratings to avoid potential threats of participants’ biased ratings. Due to the limited number of participants, the researcher reported the differences in the participants’ average and individual item scores using descriptive statistics including means and standard deviations. The average competency score of the five participants ranged from 3.08 to 3.68 out of 5.0, between the “Fair” and “Good” scales.

Peer Evaluation

The researcher collected the participants' peer-evaluation scores and open-ended written responses using the electronic evaluation rubric. The rubric was developed to see how evaluation tools influenced the quality of participants' tactile graphics. In addition to the score ratings, the participants were asked to provide open-ended suggestions and feedback to support their peers' revisions. The recommendations were incorporated and returned to the participants to help revise the drafts. After the revision process, the participants were asked to reevaluate their peers' ready-to-produce versions using the same rubric. The researcher reported the details of the evaluation results using descriptive statistics, including the scores on the drafts and revised versions per evaluation item.

Qualitative Data Collection/Analysis

Small-group Interviews

After facilitating the five activity sessions, the researcher facilitated four virtual interview sessions to collect interview data regarding the participants' authentic experiences of participating in the community activities. Brantlinger et al. (2005) suggested quality indicators for interview studies that consider 1) appropriate selection of participants, 2) reasonable development of interview questions, 3) adequate recording and transcribing of interviews, and 3) sound measures of ensuring confidentiality.

The participants were arranged into two groups to share their thoughts and experiences and frequently interact with each other. Before every interview meeting, the researcher shared the semi-structured questions to reflect on the experiences in this study and their impacts on the development of participants' knowledge and skills in creating tactile graphics (see Appendix H). The question items were shared as a reminder at the beginning of each meeting. In the first phase of the interview sessions, the researcher introduced the purpose of the interview, topics to discuss, guidelines, and time limits (Drew et al., 2007). Before the interview, the researcher obtained participants' consent to be recorded. When some participants did not want to expose their faces for privacy, the researcher had them turn off their cameras and only recorded their voices.

The recordings were converted using "Transcribe," an internal automated transcription compatible feature with Zoom teleconferencing. The software features high accuracy and allows manual correction and dictation (*Transcribe by Wreally*, n.d). The researcher transcribed the interview audio files using the intelligent verbatim transcription method (Stuckey, 2014). The technique is writing every spoken word and correcting grammatical errors and broken sentences. Several unidentified terms were clarified by contacting the participants individually to ensure precise wording. The transcriptions were only stored in a cloud folder designated for the study to secure data privacy.

The researcher implemented a qualitative data management procedure that Bailey (2008) suggested. Each participant was identified with a specific number for labeling, and timestamps were added for each turn in the conversation. Fillers were eliminated when they were deemed irrelevant to meaning. However, the researcher noted non-verbal cues such as pauses, changes in tone and tempo, and volume. Body language and orientation were also embedded in the transcription to consider deep speech descriptions. After transcribing, the researcher began the familiarization process by reading the participants' words several times. This process helped the researcher identify potential topics to code as common themes in the qualitative data (Saldaña, 2015). Throughout facilitating the community activities, =, the researcher constantly monitored the participants' learning experience and outcomes, which supported the reliability of the data.

Coding Procedure

The researcher utilized coding methods to capture themes that constructed the participants' experiences when analyzing the interview transcripts. According to (Saldaña, 2015, p. 3), coding refers to "a word or short phrase that symbolically assigns a summative, salient, essence capturing, and evocative attribute for a portion of language-based or visual data." The researcher conducted this study to explore how the community activities contributed to the professional development of TVIs related to creating tactile graphics. To answer the three research questions in this study, the protocol coding method was employed to analyze the interview data to determine if "the researchers 'goals harmonize with the protocol's outcomes" (Saldaña, 2015, p. 151). Protocol coding is a procedural coding method to categorize qualitative data based on the researcher's prescribed research questions.

As an initial step in the coding process, the researcher employed the in-vivo qualitative data analysis method to identify verbatim concepts and topics from the participants' speeches (Strauss & Corbin, 2021). The method involves labeling the transcripts 'words to identify specific topics. To automatically save the verbatim codes, the researcher used "ATLAS.ti," a web-based coding application with a graphic user interface supporting the drag-and-drop grouping function to organize excerpts of conversations per theme and topic cluster (*ATLAS.ti: The qualitative data analysis & research software*, n.d).

Next, the coding work expanded to explore the common components and patterns of participant experiences throughout the participation in this research. The researcher identified emerging codes and labeled them using specific keywords considering the purposes of the guided questions. The researcher determined the keywords by reflecting on the experience of facilitating the group work activities throughout the study. Then, the researcher built connections by creating a systemized hierarchy among the codes that emerged from the initial coding. Stable patterns were aligned with the research questions and categorized according to their connected clusters. This coding process helped refine the labeled keywords and group the codes into several related categories. The researcher read the marked codes and grouped them into several categories to overarch the keywords (Strauss & Corbin, 2021). The qualitative analysis process yielded a coding summary per the three research questions and included examples of subthemes, clusters, and verbatim code chunks identified in the participants' interview transcripts (see Appendix I).

Trustworthiness

Trustworthiness requires establishing validity and reliability in qualitative studies. Because the researcher sought vital findings that emerged from the participants' reflections, additional work was needed to determine if the qualitative data collection and analysis were credible and trustworthy. Brantlinger et al. (2005, p. 200) suggested several strategies to secure the trustworthiness of qualitative data collection and analysis of "empirical qualitative studies involving the actual collection of data in the field." In this study, the researcher employed the following strategies to secure trustworthiness: 1) data triangulation, 2) member checks, and 3) peer debriefing.

First, this study conducted quantitative data collection and analysis to see the changes in participants' tactile graphic competency and peer quality evaluations. The score changes were compared to the interview data revealing participants' experiences of how the community activities contributed to their knowledge and skills, and professional development in creating tactile graphics. Using multiple data sources in this study reduced the potential threat of the researchers' misinterpretation and biased findings.

Next, the themes and keywords were shared with the participants as part of the member checking and agreement (Padgett, 2016). The participants were invited to review and confirm the findings and interpretations of the researcher. When they did not agree with some of the analysis results, the researcher had meetings to clarify the discrepancies and partially revised the results before advancing to peer debriefing.

Then, the researcher shared the analysis procedure and results through peer debriefing with the dissertation committee members familiar with TVI practices and tactile graphics in school settings. To avoid biased assumptions and potential conflicts of interest, the researcher selected a faculty member with no interest in this study who had expertise in conducting qualitative studies in the department. She critiqued the qualitative data collection procedure, analysis, and key findings. This process helped confirm the themes and keywords by preventing potential issues such as misinterpretation and erroneous coding (Connelly, 2016).

Summary

This chapter described the recruitment procedure, participant demographics, the details of community activities, and the quantitative and qualitative data collection/analysis procedures to answer the three research questions in this study. The quantitative data included self-reported competency ratings and quality evaluation scores for the participants' tactile graphics. The data were analyzed individually to see score changes after participants experienced the community activities. Also, the researcher facilitated the interview sessions and then collected qualitative data showing participants' lived experiences of knowledge and skill development, utilization of tools, and community activities. The interview data were transcribed and analyzed using the protocol coding method to capture themes and keywords representing participants' experiences, given the purpose of the study. The next chapter reports the findings through the data collection and analysis stated in this chapter.

CHAPTER 4: RESULTS

This study explored the learning community experiences of TVIs in creating tactile graphics. This chapter consists of the community activities summary, math and science tactile graphics that the participants made, and quantitative and qualitative data results that the researcher collected and analyzed. The quantitative data includes score changes of self-reported competency and tactile graphics quality evaluation. The interview transcriptions were transcribed verbatim and analyzed to identify emerging themes and meaningful learning outcomes throughout the study activities. This chapter includes the participant outcomes and data collection/analysis results according to each research question.

Participant Outcomes

By participating in this study, the five participants created at least two sets of tactile graphics in math and science. All the creations were planned and implemented in classroom settings. The following section includes the participants' creation procedures with detailed information about each product: titles, descriptions of original graphics, draft designs, and revisions. A few drafts were converted from original graphics in textbooks or internet resources, while others were composed by the participants.

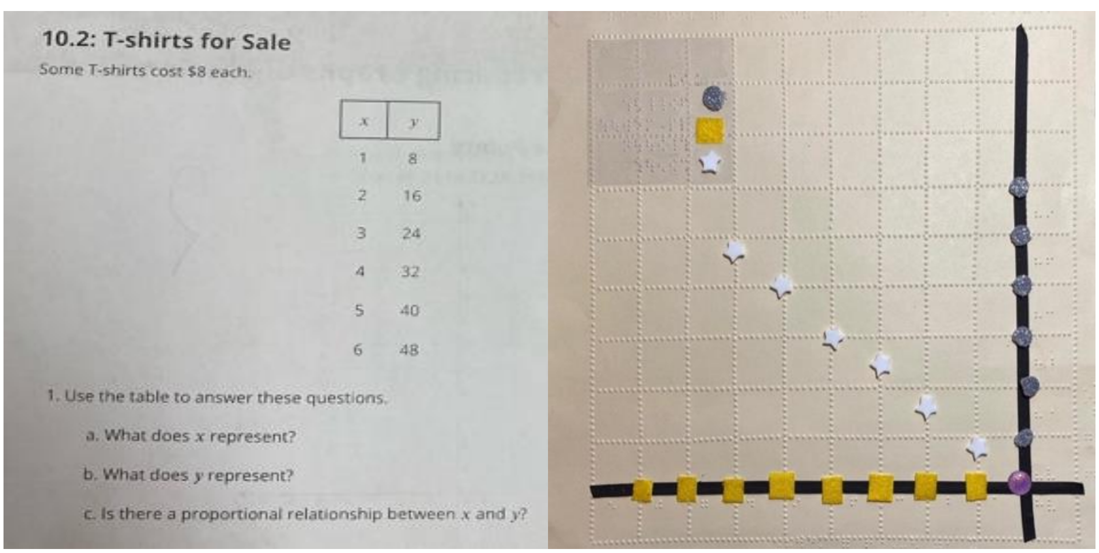
Tiffany

Tiffany decided to create four sets of tactile graphics, two for math and science each. Her first project, entitled "T-shirts for Sale," aimed to introduce x- and y-axes to her student and how to find plotted points in a bar graph. Her student was expected to use this tactile graphic to learn basic graph interpretation skills and understand coordinates and their proportional changes in values as the equation goes toward the right. The original graphic included a two-column table with numbers of t-shirts for the variable x and total costs for y. Her draft was made on standard large graph paper with braille dots. In the graphic, points on the x-axis and the y-axis were marked with purple squares and yellow dots, respectively.

She made several revisions based on the peer-evaluation feedback she received. To make progress on the first draft, she added a key for the tactile stickers in the right-hand corner. Also, she changed to a large-size APH tactile grid paper for minimum spacing. For textures, she employed her plastic gem-shaped tactile stickers with different textures and shapes, such as silver heart-shaped felts, white stars, and yellow square felts. She used a tactile splitter to represent the axes. Interestingly, she interacted with her student to control the quality of her draft and the revised version. The student feedback was also shared and discussed with the other participants while revising her draft. Her student could find the corner and keys more easily after revising her draft. Figure 2 depicts the original table, the draft, and its revision.

Figure 2

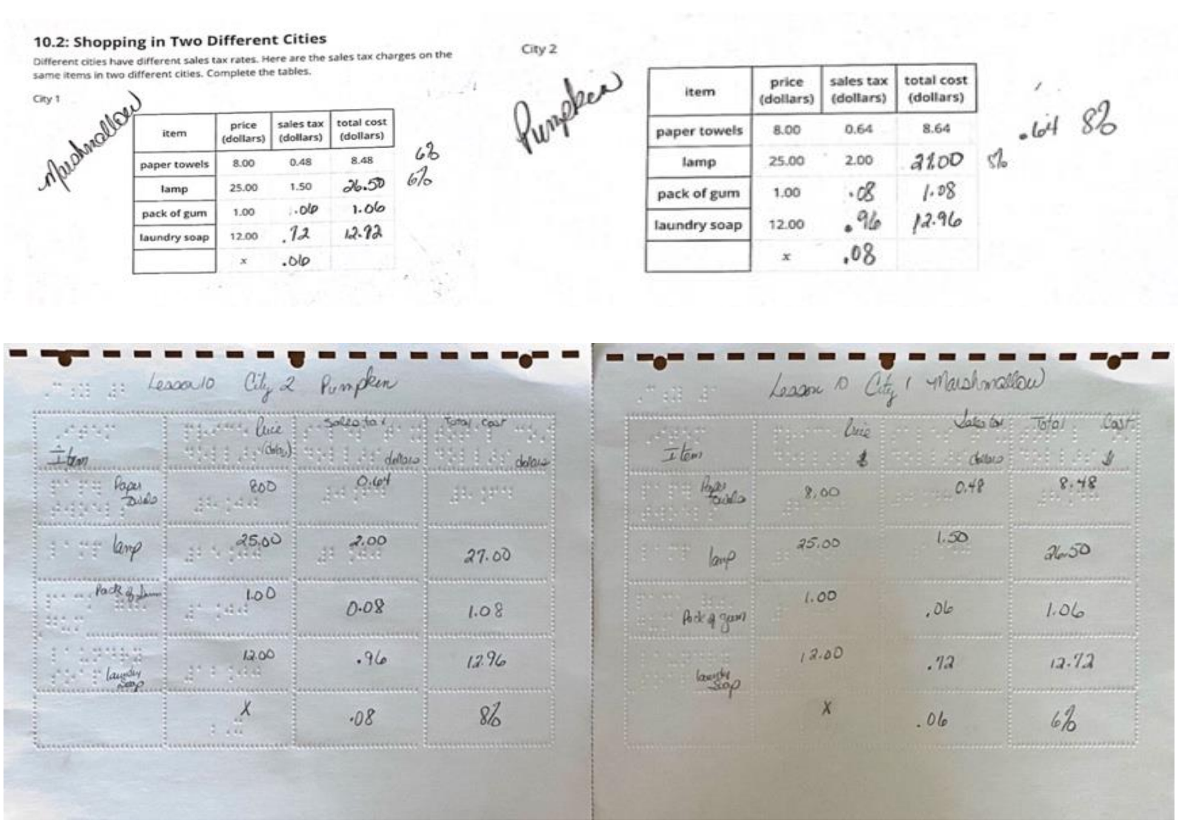
T-shirts for Sale



The second project was a standard table with four columns and six rows, entitled "Shopping in Two Different Cities." The task asked her student to calculate each city's sales tax and total costs of items and fill in the table's blanks. Using the tactile table, her student was expected to learn functions combined with a talking calculator and a set of braille slate and stylus. Tiffany used a braille embosser to draw the table with four columns and six rows. Each row represented different items, while the columns represented the cities' prices, sales tax, and total costs moving from left to right. The items included paper towels, lamps, pack(s) of gum, and laundry soap from top to bottom. She mirrored the table from the original graphic in the textbook and considered enlarging the table for spacing. Figure 3 shows the original table and its converted version.

Figure 3

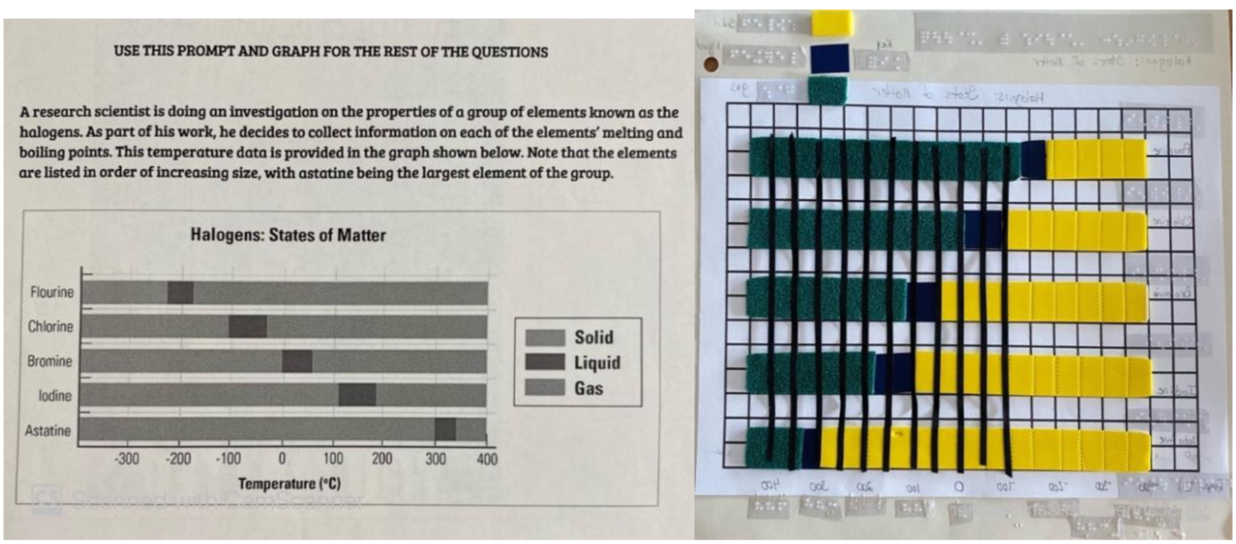
Shopping in Two Different Cities



The last graphic was entitled “Halogens: State of Matter.” The draft included different types of halogens for comparison and a number line for measurement. Using the reference data, her student was expected to answer three science questions by interpreting this tactile graph. The original graphic was a part of her student’s formal summative science assessment test. The tactile draft corresponded to the original graphic format with vertical labels indicating five elements and horizontal values showing the melting and boiling points ranging from -400 to 400 degrees Celsius. The temperature labels also had printed names. To represent the states of matter in a tactile form, she used yellow perforated foam for solid, blue matte vinyl for liquid, and green felt for gas. Thin black tactile marking tape separated units on the APH tactile graphing paper with grid lines. Figure 4 depicts the original graphic and her final version of the tactile chart.

Figure 4

Halogens: State of Matter

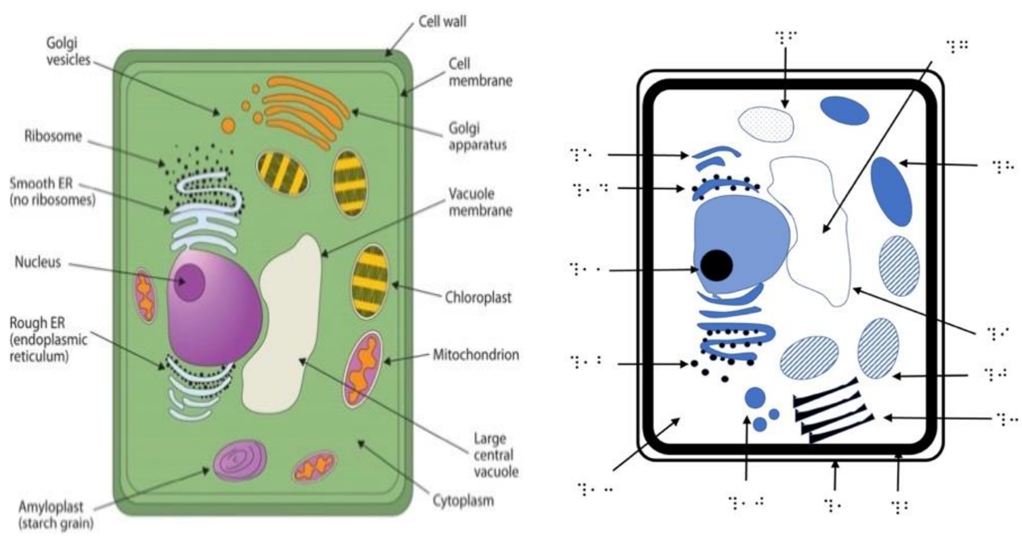


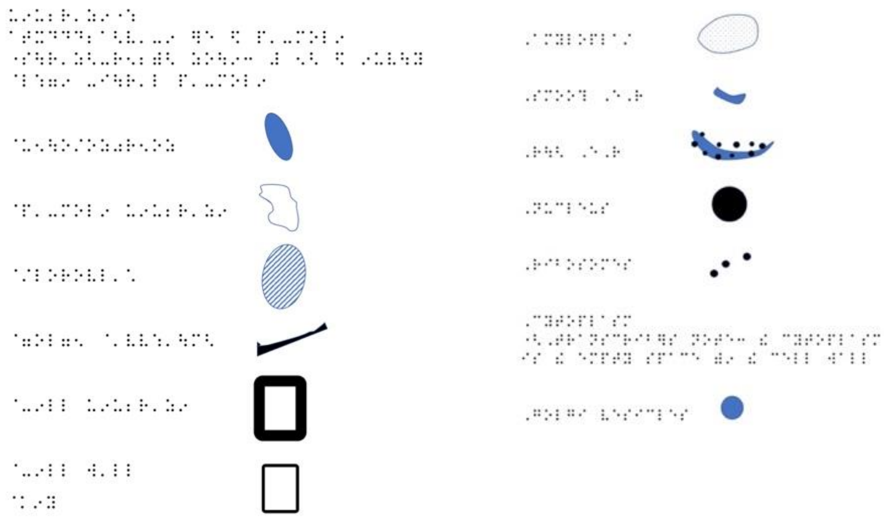
Shawn

Shawn created two tactile graphics in math and science. His first graphic was created to teach a junior-high student the elements of animal cells in biology. He imported an image file that visualized a cross-section of an animal cell, then adapted it to a tactile graphic with different textures and lines (see Figure 5). Several elements were simplified, including ribosome markers and texture fillings. He used numeric keys to represent each element's full name on an additional page. He varied the thickness and texture of lines and areas to represent various elements within a cell. His revision improved the key notes. The key had initially consisted of numeric keys and their corresponding full element names; however, his revised legend included a number, the full name of the element, and the element's corresponding texture on the same line, which helped the student identify and locate each component of the cell layout. Also, the arrow points of indication lines were enlarged to enhance tactile recognition.

Figure 5

Animal Cell Cross-Section

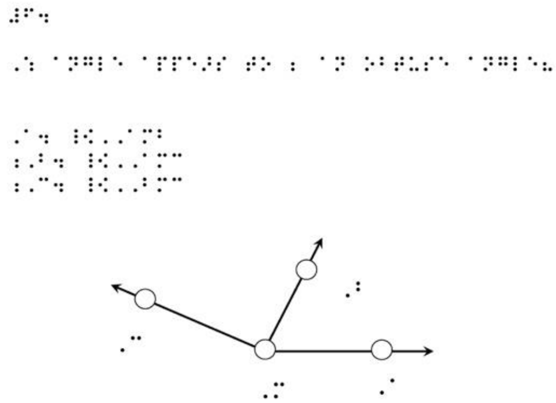


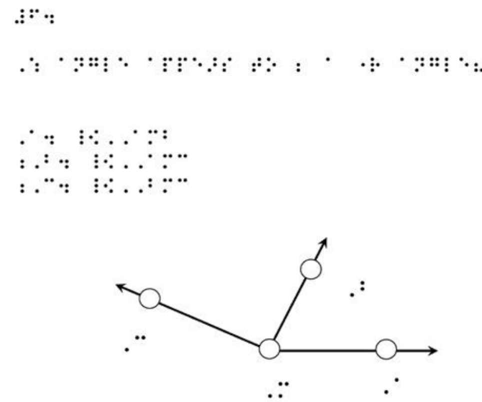


His second graphic was created to teach his junior-high student obtuse and right angles in geometry (see Figure 6). Using computer-assisted drawing tools, he drew bold lines representing angle arms and non-filled small circles to mark vertices (joining points of the two arms) and the endpoints of each arm. Each circle had an uppercase alphabetic key ("A," "B," "C," or "M"). He followed the Unified English Braille (UEB) for math notation his student was introduced to for math learning. To print the tactile graphic with braille, he used SimBraille, a specialized font of printable braille characters to represent dot combinations available on computer keyboards (*BRL: Braille through remote learning*, n.d.).

Figure 6

Obtuse and Right Angles



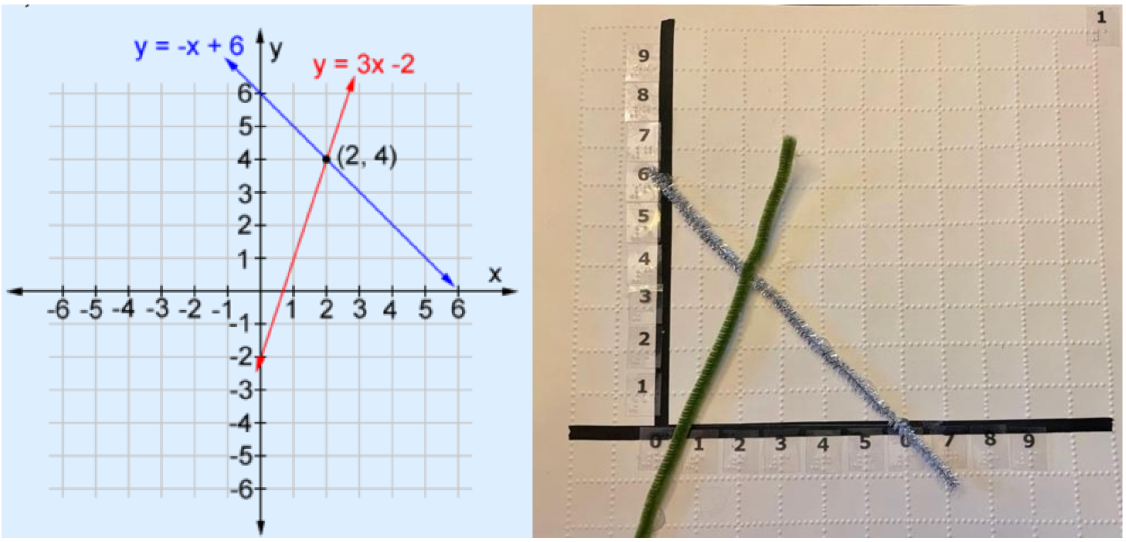


Perry

Perry created two tactile geometry graphics, entitled “Intersecting Lines” and “Congruent Triangles,” for her 10th-grade student whom she worked with as an itinerant teacher. Her student was to learn equations in geometry and tactile graphic reading skills using these tactile graphics that corresponded to the standard quadrant format. The original drawings came from the student’s math textbook. The first graphic included two lines on quadrant 1 with an equation (see Figure 7). She intentionally zoomed in on quadrant one on the APH coordinate grid paper and eliminated the other quadrants for simplification. The X and Y axes of the quadrant were made of black tactile stickers, and the origin (0, 0) was marked using a tactile sticker with a different texture. To present the equation lines of “y=3x-2” and “y=-x+6,” she used black-colored yarn with the two equations at the top of the two graphs. Based on the peer evaluation feedback, Perry added braille labels to each value of the two axes, which helped him understand the X and Y coordinates. To avoid confusing the two lines made with yarn of the same color and texture, she replaced them with different types of pipe cleaners. The equations were moved to a separate key page to help her student easily differentiate the lines. Figure 7 depicts the original textbook graph, her draft, and revision.

Figure 7

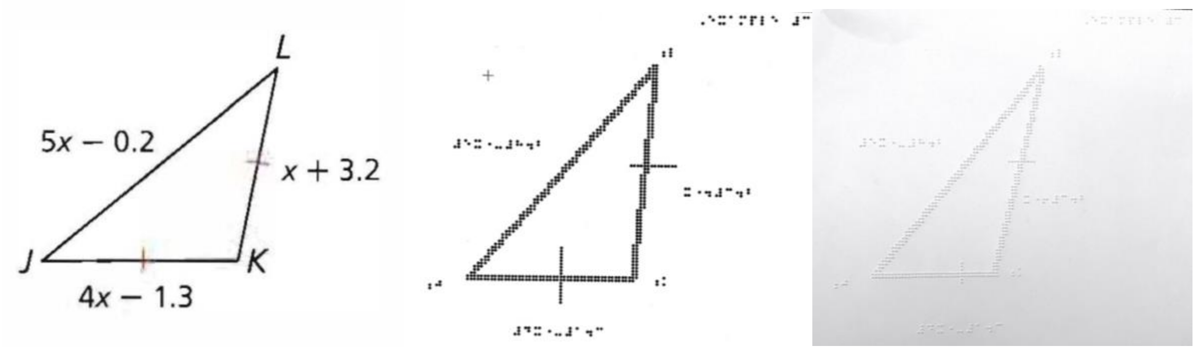
Intersecting Lines



Perry's second graphic was a braille-printed triangle with congruence lines. Using this tactile triangle, she intended to teach her student to find the side lengths of the triangle by substituting the value of x into the expressions in the graphic. She used QuickTac, a braille drawing application compatible with a braille embosser in her school district. She mirrored the triangle from her textbook's original graphic and converted it to a tactile form using QuickTac's drawing feature. She used double-layered braille lines to present triangle lines, whereas single-layered tick marks represent the congruent lines. Each angle's vertices included letter indicators according to UEB math notation. She made minor revisions by enlarging the congruence lines and making them more uniform. The resizing helped increase the resolution of the diagonal lines. The difference in thickness of the triangle and congruence lines enabled her student to understand which lines were part of the shape and which were congruence markings. Figure 8 shows her original graphic, draft, and revised version printed using a braille embosser.

Figure 8

Congruent Triangles

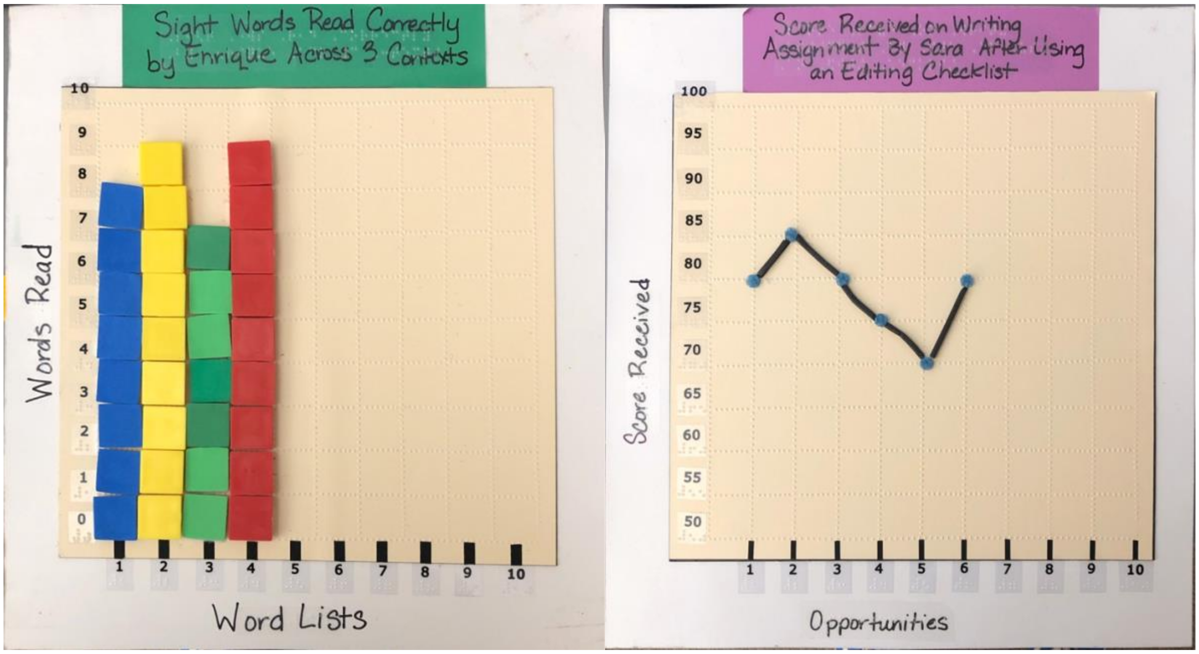


Kiley

Kiley created two interactive bar and line graphs to document her student's scores on writing and reading assignments. She intended for the student to use these graphs to record scores on literacy assignments and then read the charts to see progress as data accumulated. Using APH braille grid paper, she employed standard-type graphs that consisted of a centered title at the top of the page, a horizontal x-axis at the bottom, and a vertical y-axis on the left. Her student could have up to 10 opportunities to document scores ranging from zero to 10. Kiley used colored blocks with differentiated textures for bar graphs and black-colored yarn for line graphs. Each data point on the line graph was a tactile sticker to give a differentiated texture from the line. Print labels were added in braille. Figure 9 shows her draft and its revision.

Figure 9

Interactive Bar and Line Graphs for Literacy Assignments

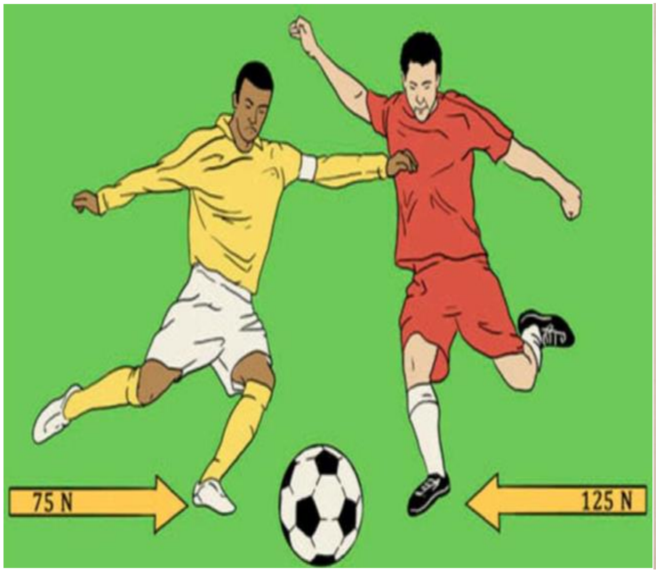


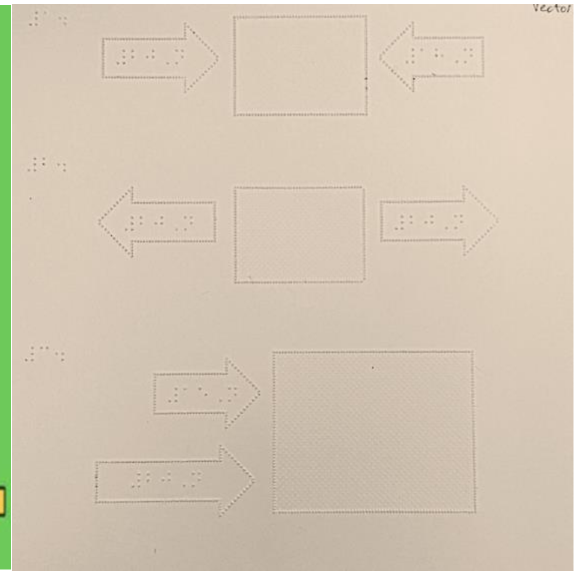
Kamila

For her middle school student, Kamila wanted to convert an original graphic that illustrated vector dynamics in physics. She intended to simplify the diagram by eliminating non-essential information because her student had basic tactile graphic reading skills. She resized her tactile graphic to fit within three square inches. First, she eliminated the redundant data from the textbook illustration for simplification. Instead, she used square boxes representing objects in the middle of her graphic. She located two vector arrows on the object's sides representing the power of forces moving in a specific direction, such as left or right. Each arrow had a braille number indicating the power of each force (e.g., 18N and 20N). Figure 9 depicts the original graphic, the draft, and its revision using a braille embosser.

Figure 10

Vector Dynamics





While planning and creating these tactile graphics, the participants interacted with other TVI participants and the researcher in building a learning community. The study activities supported the participants in sharing available online and community resources as well as experiencing the systemized creation procedure of tactile graphics using various tools, including decision-making tools, the planning sheet, and the evaluation rubric. While facilitating the study activities, the researcher collected the data to answer the three research questions of this study and obtained the findings shown in the next section. For learning community interactions, the participants utilized multiple online formats including regular virtual meetings, electronic discussion group/email, and clout storage to share the creation progress.

Research question 1: What are TVI's experiences of community activities related to skill development in creation of tactile graphics?

Self-reported Competency Evaluation

The first research question investigates how the learning community activities of this study changed the TVI participants' knowledge and skills in creating tactile graphics. The activities provided opportunities to discuss each tactile graphic draft and its revisions to ensure quality. While planning and editing, the participants exchanged creative ideas and suggestions based on the concrete items of planning and revision, such as the use of different areas, appropriate lines, appropriate labels/symbols, and different creation methods. To answer the research question, the participants were asked to evaluate their competency scores before and after participating in the activities and then reflect on their experiences in interview sessions with the colleagues and researcher.

The competency evaluation consisted of essential items to consider when converting original graphics into tactile forms (e.g., knowledge of standards; simplification/elimination; use of lines, symbols, and labels; and proficiency in computer-assisted methods). The researcher collected the same test score after completing to create tactile graphic products to see if there were score changes. Each item was rated on a 5-point Likert scale ranging from "Never tried" to "Very good." The participants completed the evaluations before and after participating in the community activities. The average scores on the pre- and post-test evaluations ($N = 5$) were 3.10 ($SD = 0.87$) and 4.08 ($SD = 0.71$) out of five that showed positive learning outcomes on the competency items.

Even though the researcher could not determine if there was a statistically significant difference due to the small sample size, the changes in scores represent 1 unit of scale from "fair" to "good." Specifically, the "usage of checklist" item showed the highest score increase. Details of each participant's average competency score ratings are in Table 4.

Table 4

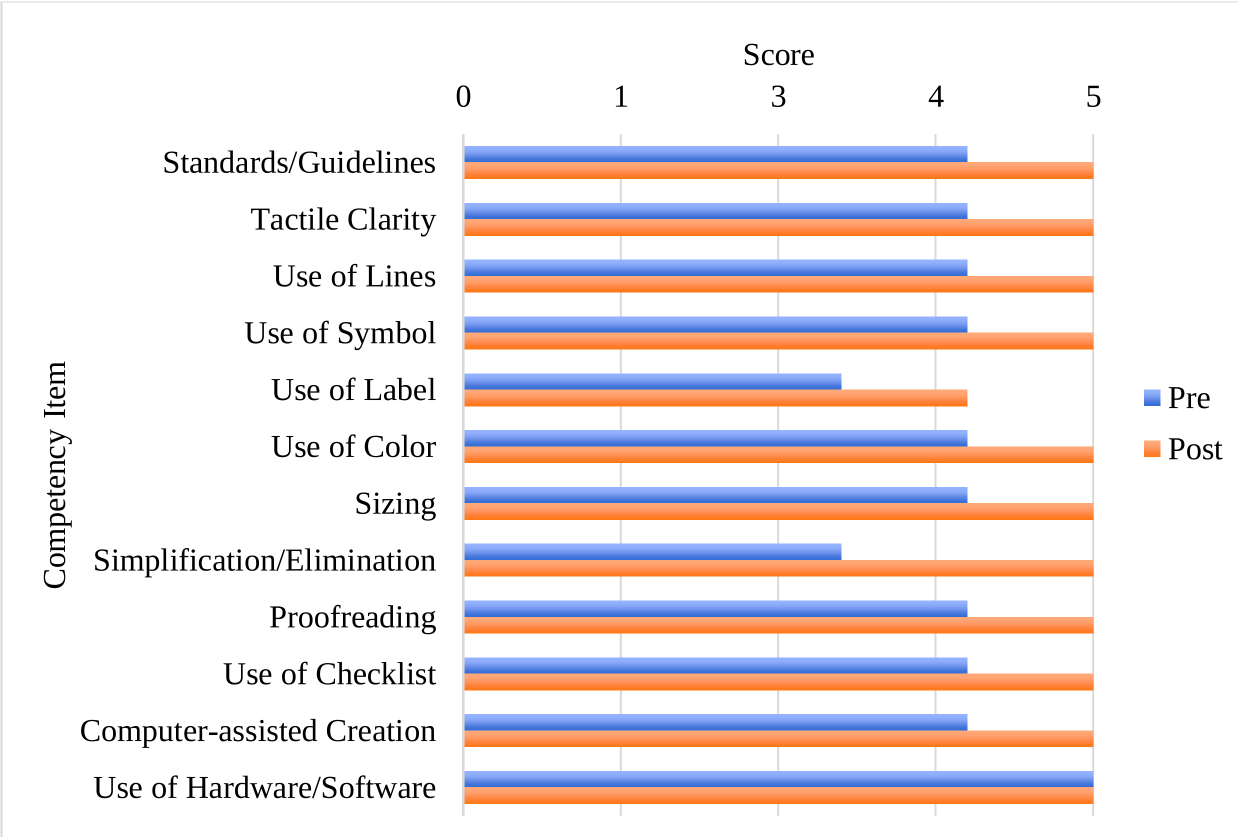
Descriptive Statistics for Pre-test and Post-test of Participants

	Pre-test		Post-test		
	Mean	SD	Mean	SD	Mean-score Difference
Tiffany	3.90	0.51	4.90	0.29	1.00
Shawn	3.40	1.08	3.30	0.78	-0.10
Perry	3.80	0.45	4.10	1.08	0.30
Kamila	2.50	1.40	4.20	0.72	1.70
Kiley	1.40	0.90	4.00	0.67	2.60
Sum of Tests	3.10	0.87	4.08	0.71	0.98

Tiffany’s average pre- and post-scores were 3.90 (SD = 0.51) and 4.90 (SD = 0.29) respectively. Her average scores were higher than other participants on every evaluation item other than the use of hardware and software. She rated herself as “fair” on the use of labels and simplification, which was lower than her ratings on the other items. However, her ratings on labels and simplification increased between the pre- and the post-test.

Figure 11

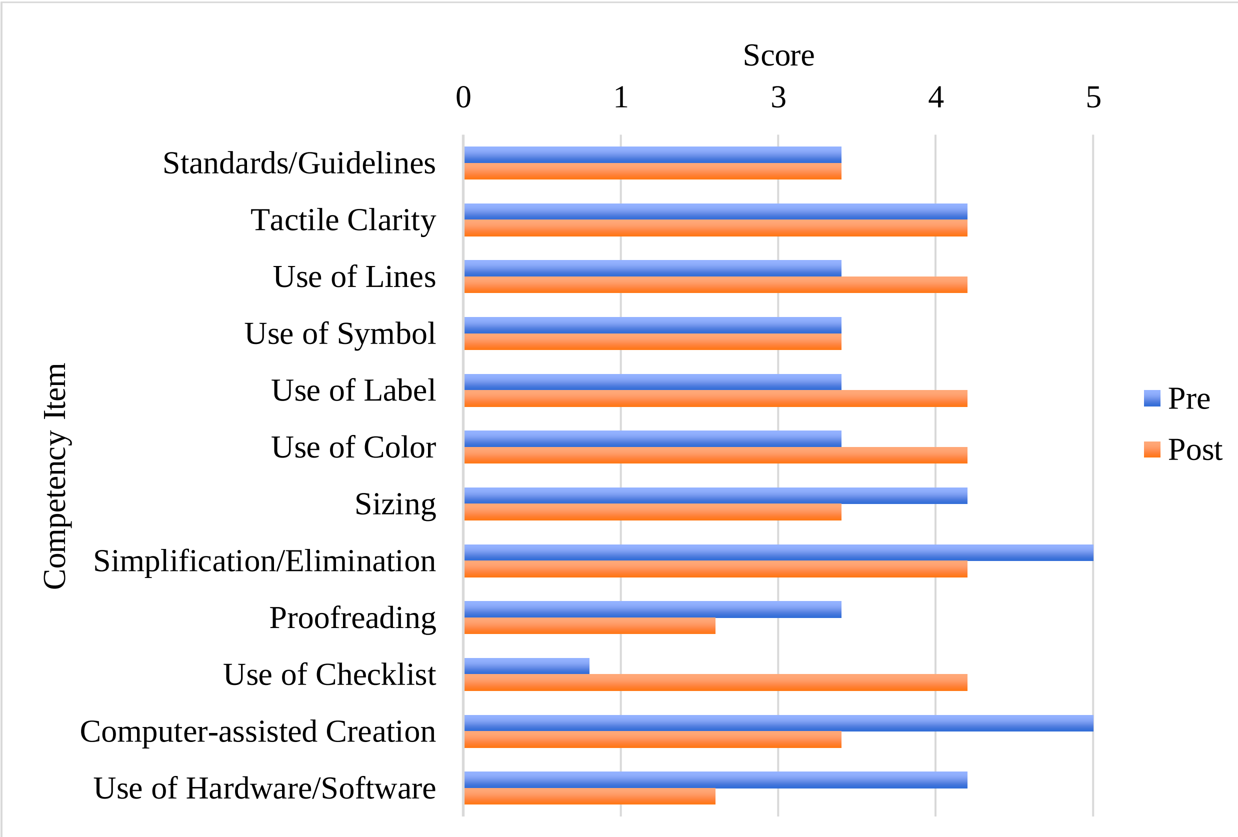
Changes in Self-reported Competency Scores: Tiffany



The average pre- and post-scores of Shawn were 3.40 (SD = 1.08) and 3.30 (SD = 0.78) respectively. His scores increased on the items of using lines, labels, and colors. Also, he initially rated his checklist use very low; however, his post-evaluation score on that item showed the highest increase with three points of difference. The items related to computer-assisted creation and use of hardware/software decreased during the post-evaluation even though he was initially confident with technology and experienced in utilizing computer-assisted methods.

Figure 12

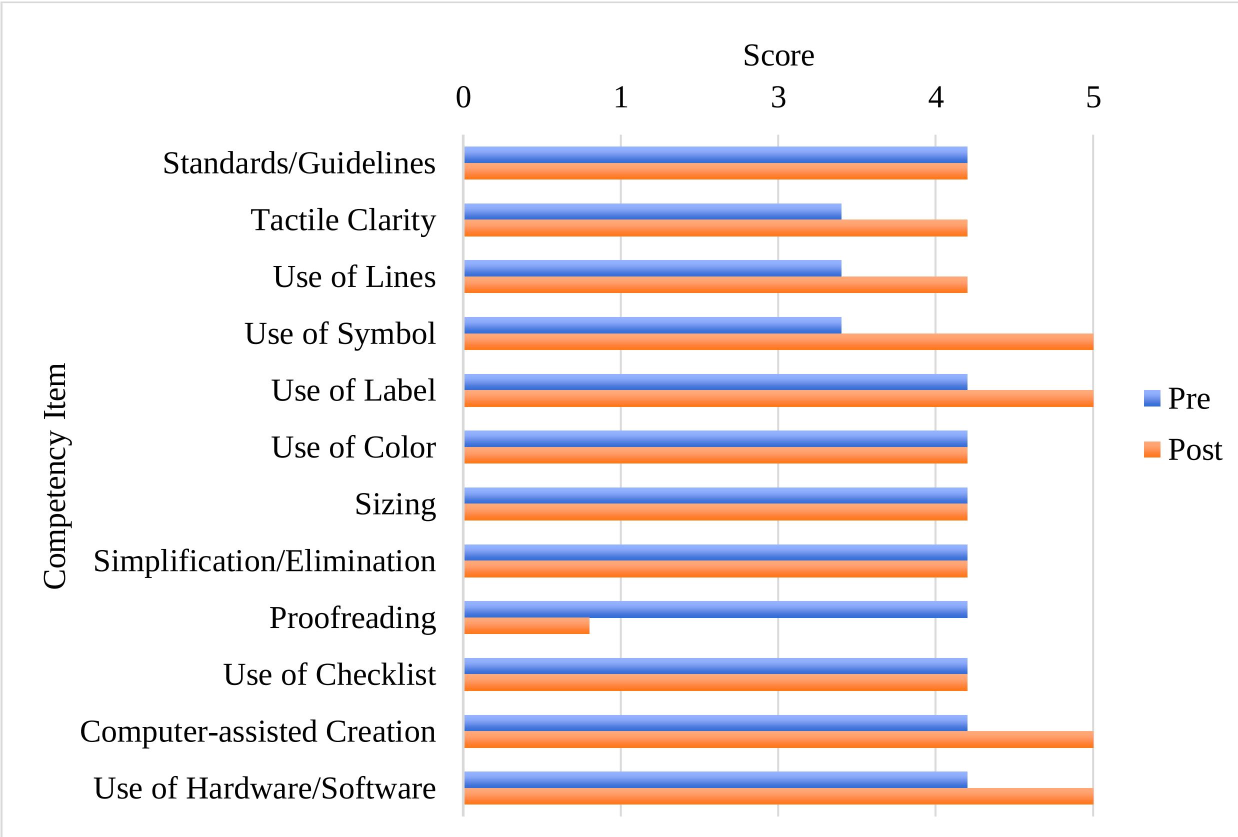
Changes in Self-reported Competency Scores: Shawn



Perry's pre- and post-scores were 3.80 (SD = 0.45) and 4.10 (SD = 0.08) respectively. She recognized improvement on the items related to tactile clarity, use of lines, symbols, and colors, as well as technology items. In contrast, her rating on proofreading decreased by three points after participating in the activities.

Figure 13

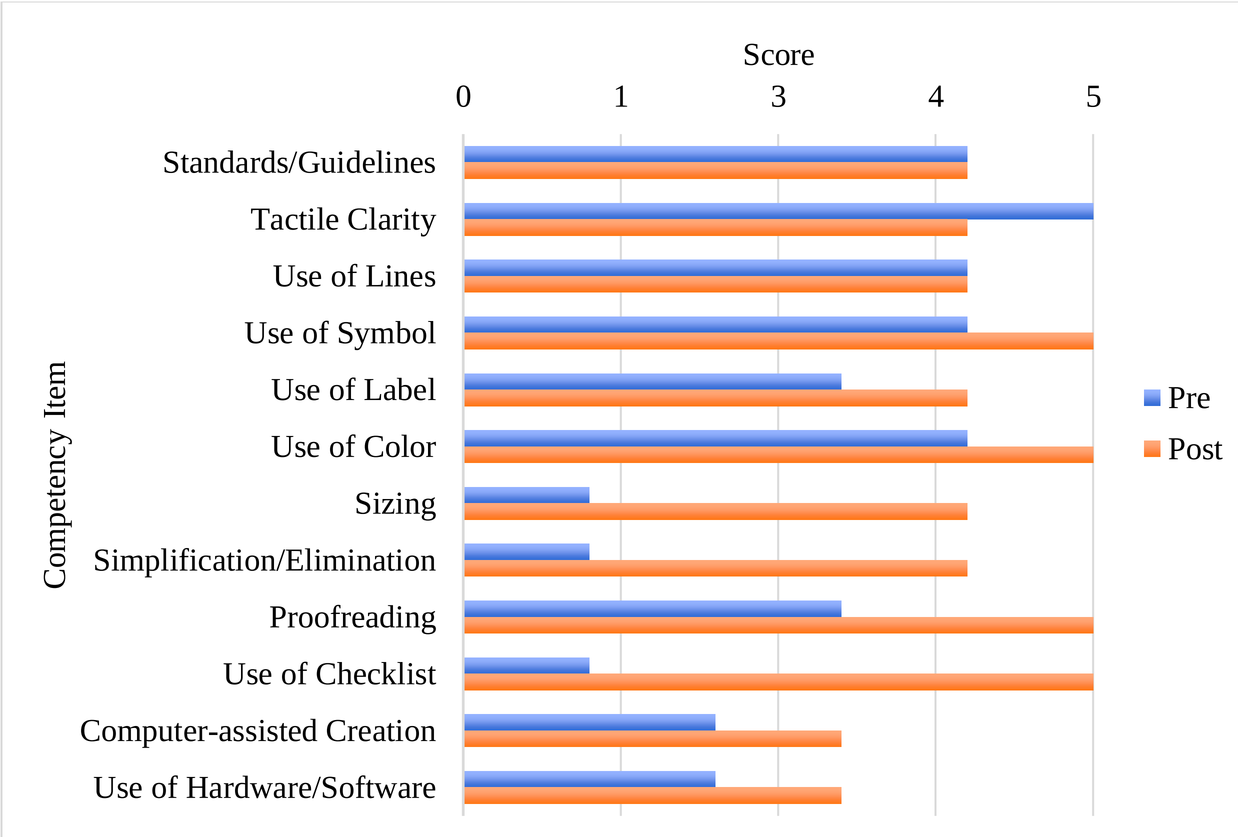
Changes in Self-reported Competency Scores: Perry



The averages of Kiley's pre- and post-scores were 2.50 (*SD* = 1.40) and 4.20 (*SD* = 0.72) respectively. Out of the 12 items, she self-reported improvements on nine items after participating in the community activities. Among the score increases, she recognized the highest increase in sizing, simplification/elimination, and use of a checklist. Her scores changed by more than three points to" Good" and "Very good." The only score with a negative change was her self-rating on tactile clarity, which decreased by one point.

Figure 14

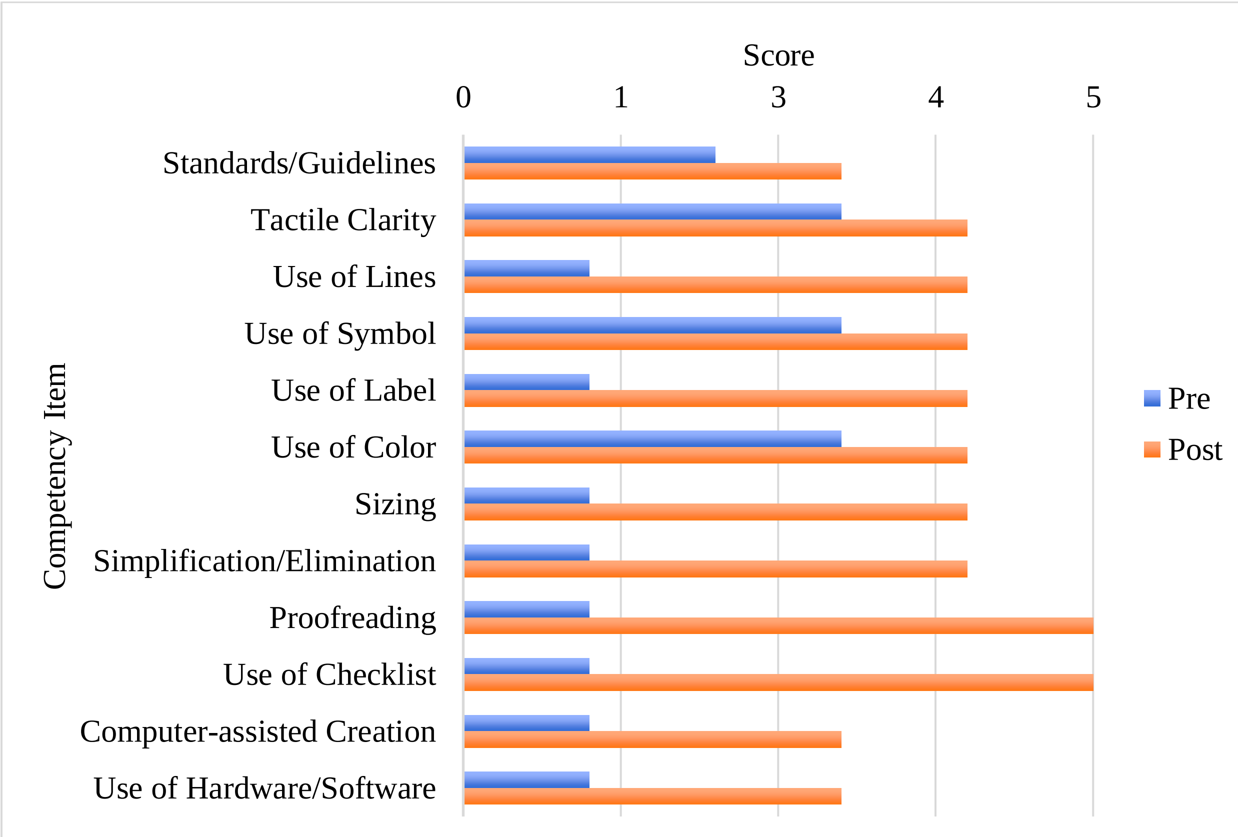
Changes in Self-reported Competency Scores: Kiley



The average pre- and post-evaluation scores for Kamila were 1.40 (*SD* = 0.90) and 4.10 (*SD* = 0.35) respectively. On the pre-test, she gave herself a score of 1 on eight of the 12 items. The items 'scores improved on the scale ranging from "good" to "very good" over the participation in the study. In particular, the items related to the revising and editing increased the most. Sizing and simplification scores also showed a three-point increase after she experienced revising her vector tactile graphics.

Figure 15

Changes in Self-reported Competency Scores: Kamila



Qualitative Findings

In addition to competency scores, the interview sessions allowed TVI participants to reflect on their experiences of learning community activities and authentic interactions with TVI colleagues for knowledge and skill development. Following the protocol coding procedure, the researcher coded the transcripts to capture specific themes the participants agreed upon. Three themes emerged from the data analysis regarding knowledge and skill development. The participants reflected that the activities helped the TVI participants 1) become aware of the creation process, 2) ensure the inclusion of essential components, and 3) increase their productivity in the practice of creating tactile graphics. Each theme that emerged from the interview transcripts is described in more detail in the section below.

Become Aware of Systemized Creation Process.

TVI participants were asked to share what was most beneficial for their knowledge and skill development in their community interactions with other TVIs. During the interviews, they reflected that the interactions made them more aware of the systemized creation process, from planning to revising, so they could apply the ideal procedure to their practice. In the words of Tiffany, Perry, and Shawn:

> *"I really have known and read it, but I really didn't apply this procedure. This experience has helped me to implement that (the creation procedure) more effectively… I don't fill out that sheet for every project. But mentally, …you get your pre and post. I'm going to do to plan and … make sure that I've crossed all the points."* (Tiffany)

> *"It's really more of this kind of bringing what you learned in school when you're getting your certification. Oh, these are the rules and making high-quality tactile graphics." (Perry)*

> *"I think this study was more formal training, so connecting with other TVI colleagues was helpful to review the standardized checklist and procedures as to what makes the best possible tactile graphics." (Shawn)*

Tiffany and Perry learned the creation procedure through college programs and continuing education opportunities while working in the field. Perry was involved in reviewing commercially-produced tactile learning materials for students with VI. However, her creation procedure used to be scaled down in her practice. In the last phase of the interactions, she articulated, "*Skillwise, I think more of that awareness of what is the best practice, versus what we know. There's reality, but I think that's more focused on this practice and opened my eyes to things.*"

Ensuring Essential Components of Tactile Graphics.

The participants also agreed that the community experiences with other TVIs helped ensure consideration of essential components for high-quality tactile graphics. Using differentiated tactile representations is essential for creating tactile graphics, however excessive textures can lead to challenges in distinguishing close textures properly. For example, BANA and APH guidelines suggest using no more than four textures in a single tactile graphic. According to peers' comments, several elements of the participants' drafts were overwrapped and not differentiated from adjacent elements. Shawn and Kamila converted the original graphics of an animal cell and vector dynamics from science textbooks, and the original graphics looked cluttered with overwrapped graphic items. Participants recognized that they made progress in making the different elements of their tactile graphics distinguishable. The following bulleted items are the learning outcomes of TVIs regarding essential components for high-quality tactile graphics.

- Knowledge of essential considerations for tactile graphics
- Utilizing different tactile representations of lines and areas
- Using no more than four textures in each tactile diagram

- Separating images with no clutter
- Rearranging the items without compromising the integrity of the original graphic
- Maintaining appropriate spacing between tactile elements
- Determining the size and color of tactile graphics
- Proofreading braille texts for accuracy

Increasing Productivity in Practice.

Participants addressed their challenges in budgeting their time. The reality of time limitations in school settings differed from the participants' training for tactile graphics, resulting in a gap between ideal and current practice. They used to create tactile graphics on the fly even though high-quality creative work demands much time and effort. The participants agreed that time availability is a significant factor when providing converted learning materials for students with VI. The participants shared that increasing productivity was an important learning outcome to meeting last-minute demands. Two participants shared as follows:

> *"A lot of times I am creating on the fly… Because I'm overwhelmed and you get things at the last minute, and you want to do what's best for the student …. but I really wanted some guidance and directions on how to be better at doing that."* (Tiffany)

> *"The flow chart (decision-making tree) has just been part of my thinking without realizing that it's not like… because again it's that balancing act of time. I wasn't a material person … But it really comes down to time and availability in need"* (Perry)

Research question 2: What are TVI's experiences of community activities regarding utilizing different tools for creating tactile graphics?

The participants utilized various tools throughout creating each draft and its revised version. The decision-making tree helped determine if a visual graphic was appropriate for conversion into a tactile form. The planning sheets and checklist ensured that participants considered the essential items for creating quality tactile graphics. Participants discussed their drawing ideas and original graphics in the planning step based on the items for simplification, re-sizing, separation, areas/lines/points, and symbols/keys. The evaluation tools supported the participants in improving their drafts using quantitative rubric scales as well as qualitative written feedback. When the participants were asked about utilizing the tools for planning and evaluation, they addressed the following three themes: 1) planning tools for outlining expectations, 2) evaluation tools for quality control and 3) existing source files and commercial kits with limitations.

Qualitative Findings

Planning Sheets for Outlining Expectations.

First, participants said that the guidelines provided a well-established outline and expectations for what should be considered and improved at each step of the creation process. When they struggled with decision-making, the rules and examples in the guidelines and standards assisted them with quality control. The participants specified what helpful the different tools when creating high-quality tactile graphics as follows:

"Decision-making tree helps you better understand… if you're unsure, you can follow a pre-made decision for yourself… I love compiling resources, so the resource was

the most helpful thing I took away from the entire study… I was using the tactile graphic planning sheet where I could better understand things like resizing, consolidation or separation and understand the different areas and textures that were used in ways that can be improved….” (Shawn)

"It's (guidelines/standards) good to know what's expected and what's like a standard and then how much I want to like maneuver it for my students, so that was the most exciting part like the standards and the guidelines." (Kiley)

“Planning sheet for thinking about what's going into this graphic and being more aware of it…being cognitive of what you're doing your graphics so that I learned something new… when it becomes second nature, just like anything else you can take it in stride.” (Tiffany)

Rubric Evaluation Items for Quality Control.

Participants agreed that they used the checklist and evaluation rubric to ensure their creation steps were consistent. The evaluation tools provided clear criteria for determining if their drafts and revisions were appropriately created. In the editing phase, the participants preferred to use the rubric evaluation items instead of reviewing the guidelines and standards. They agreed that the rubric was a more efficient tool for ensuring quality than guidelines/standards with general rules. When the participants were asked which tool was most beneficial for creating tactile graphics, three participants described the tools for ensuring the inclusion of essential components in their graphics:

"Mine would be the editing part, using that rubric… it gives you that review and proofreading to make sure that every step is clear and says what you wanted to say and that thing" (Kiley)

"Like a review, like a quick I did all my textures distinguishable, my spacing is good… I didn't necessarily go across all for I thought, some of those were a little bit difficult to distinguish or like really pinpoint where my thing was on." (Kamila)

Also, Shawn and Perry talked about how they used the rubric as a checklist to complete their creations in the last phase of editing as follows:

"I've only done that in informal training, so what helped me the most was learning a little more systematic black and white checklist of what to look for when preparing a tactile graphic, what to look for during creation, and what is good for after creation and then instruction, so I thought that was helpful all of the resources." (Shawn)

"Rubric to give us a little bit of sense of relief whenever we can't give out something 100%… if I have that rubric and I can say I missed on this." (Perry)

Existing Source Files and Commercial Kits with Limitations.

Through the activities, the participants and researcher completed a list of online archives providing ready-to-use source files as resources. The researcher introduced some tactile image libraries at the early phase of this study, but none of the five participants used these resources.

The participants reflected their perspectives and experiences about the source files and commercial tactile graphic kits provided out of school settings. They noted that the resources were basically good and met the essential criteria for high-quality tactile graphics; however, the participants found it challenging to adapt the images because of braille, hardware/software compatibility, less flexibility, and relevance to student needs. The participants were not accustomed to using the source files and did not recognize the sources as valuable resources. Instead, they preferred using manual creation methods or computer-assisted tools to draw the original graphics.

Several reasons the participants felt reluctant to use the source files were identified. First, the participants reflected that many existing source files were irrelevant to their student's academic needs or grade levels. Perry felt challenged to determine if a resource was appropriate for her students and thus relied instead on manual creation methods. Perry and Tiffany discussed the difficulties of editing the sources according to their student's individual needs:

"…It would be hard to really decide what images are a value would be used, across the board, you would think I keep saying the parts of a flower right or like maybe anatomy parts of the body, but then there are other things that are available like APH makes science tactile graphics that you can get with like life science and physical science." (Perry)

"I used to use TactileView for most of mine, still, I have a hard time I very rarely can import something that I can use this and then I have to evaluate I'm going to have to tweak this. That tweaking is going to take longer than it is to just create it from scratch." (Tiffany)

When the existing resources did not perfectly fit the needs of all students with VI, TVIs inevitably needed to adapt or modify the resources for their students' individual needs. Tiffany pointed out a limitation of the resources when providing tactile graphics for state-level tests and textbooks. She was required to create tactile graphics corresponding exactly to visual representations that the tests included, however discrepancies existed in the original graphics. Also, the math and science curriculums varied from one state to another; thus, tactile image samples provided by APH or other agencies did not work for her students.

Perry and Kiley pointed out that not every tactile graphic was appropriate for their students' learning areas and grade levels. The existing resources provided by the agencies were high in quality however Kiley acknowledged that the source files were not relevant to individual students and teachers as follows: *"Your list of common images might be totally different than mine based on experience and curriculum."* She, now serving students with VI and cognitive disabilities, pointed out the source files were mainly developed for academic students. She said, *"Most of them are too high concepts in the first place… I'm not teaching my kids about rockets or plant cells or whatever. If it is one very simple part of it, most of them are not at the right level."*

Second, the TVIs perceived those existing resources were difficult to modify. To use images in their classrooms, they had to consider if they were appropriate or needed to be edited. Editing required extra time and effort, so the participants preferred to convert the original graphics using braille or computerized drawing methods. Regarding usability, the participants wanted to use source files of basic concepts rather than complex and high-level concepts; thus, the participants suggested basic or straightforward types of tactile images that can generally be used more flexibly. Perry and Tiffany shared the following observations:

"Okay, so in the textbook, that whole-cell images there, but what is the teacher really going to talk about? Is she going to talk about this whole cell or … on the mitochondria or whatever…? When we go out to those repositories, they're great that they're there, and maybe they're helpful for someone." (Perry)

"We're not talking about a whole software program but to be able to do that and then that would create your base and then you might have to do a label or two, or add one or two things, but something that is a standard for every kid that's learning that particular… Just a standard almost like a blueprint, and then we could add, that would be very helpful then you have a base to start with." (Tiffany)

Lastly, but importantly, the math braille notation issue was captured. The participants pointed out that the online sample resources inevitably needed a critical modification with a specific braille notation for math tactile graphics, either the Nemeth code or Unified English Braille (UEB). Math tactile graphics include a braille notation, either Nemeth or UEB. Ideally, both options should be available for broader use. However, many tactile graphics do not provide UEB options, so extra UEB work discouraged Perry and Tiffany from using specific resources. They articulated:

"I've gone out and spent more time searching for something on there that doesn't work versus making it myself… My students are doing UEB, so I would have to take hers and then edit it. So that's I think a limitation.", "I'm more proficient in UEB. South

Carolina University presented a bunch of tactile graphics, but it was all Nemeth, so it was basically creating textured graphics using Nemeth, and I'm like, I need that UEB…."

And nine times out of ten, I need to create it from scratch, because it's just I can't manipulate the program the way I want to, or I can't Nemeth for UEB in Delaware…." (Tiffany)

For these reasons, the participants preferred to convert original graphics with simplifications and eliminations using a manual creation method instead of modifying sample images to meet their students' academic needs. In this study, the participants recognized peer-created samples as more essential resources for personal repositories than source files provided in the online repositories. Many of the source files TVIs found did not match the students' grade levels, which were relatively less recognized as valuable resources than peer-creations.

Hardware/Software Needs Compatibility.

Inflexibility was also an issue with the use of hardware and software. The two participants who used computer-assisted methods agreed that hardware and software allowed them to produce tactile graphics in a limited amount of time. Compatibility was an important factor when utilizing hardware/software for tactile graphics. Perry did not utilize the resources because they were limited to specific software and were not compatible with other software that she used to use. Even though she became confident with handling "QuickTac," a tactile graphics drawing tool, the resources may not have been usable with another piece of software, or the conversions may have taken a long time. Perry pointed out that computer-assisted methods have the advantage of creating "*a bunch of graphics in a short amount of time on the fly.*" However, the benefits are only available if drawing and braille software are compatible. She enjoyed using Quicktac because she could easily "*put all that into Duxbury and then just translate it and then copy that Braille text from Duxbury right into Quicktac*" because the two programs

Research question 3: What are TVI's experiences in participating in a community when creating tactile graphics?

The community activities allowed the TVI participants to share common interests and available resources that they later retained. Based on their current knowledge and skills, the group exchanged feedback and comments for improvements throughout the creation process. The participants discussed decision-making and problem-solving challenges by utilizing tactile graphic tools. The community interactions expanded their network of colleagues with shared goals and knowledge related to tactile graphics to be used in the participants' teaching practices.

Fieldnotes Summary

The activities in this study were developed and facilitated for specific TVI participants interested in math and science tactile graphics. At the first meeting, the participants shared common goals and interests related to the study. Even though they worked with students at different grade levels and in other content areas, the diversity enriched the expectations of this study's learning outcomes. The participants were interested in math and science for 7th to 10th-grade students and transforming visualized data representations into tactile forms. Also, two participants were interested in utilizing technology-based creation methods such as QuickTac and the Thermoform machine. With these shared goals and interests, the participants enriched their knowledge of diverse creation methods within the systemized procedure that the researcher facilitated.

The community experiences of participants led to learning knowledge and skills in tactile graphics and employing their creations for their student's math and science learning in the classroom. The outcomes were aligned with the knowledge of practice that highlights the close relationship of both aspects of learning. Knowledge and skills acquired in the community activities and interactions between colleagues led to utilizing TVI-created learning materials based on a creation procedure. In addition, the researcher observed the pros and cons of virtual settings where the participants interacted and how these characteristics influenced participation in the community activities throughout the study. First, the participants engaged in interactions with colleagues across the nation: two were in Delaware and Pennsylvania, and three were in Arizona. They regularly met and, through their interactions, provided feedback, shared resources, and reflected on learning outcomes. Also, the participants selected their preferred communication platform(s). The researcher surveyed all participants about their preferences based on availability and previous experience and then utilized selected communication methods, including email and Google docs. Electronic documents and forms provided flexibility and accessibility to eliminate potential barriers to participation.

However, building solid relationships and communication among group members was challenging as the online meetings occurred once every few weeks. The researcher introduced new strategies to elicit participants' engagement and interactions with colleagues. The researcher reminded the participants to participate more frequently, clarified the instructions for activities, increased one-on-one interactions using pair activities, and maintained consistent groupings. Also, some of the participants faced technology glitches when accessing the electronic documents, joining the meetings, and completing individual assignments. For example, two participants who used their business accounts had challenges opening Google Docs, so the researcher had to resolve the issue by sending the resources to those participants via email.

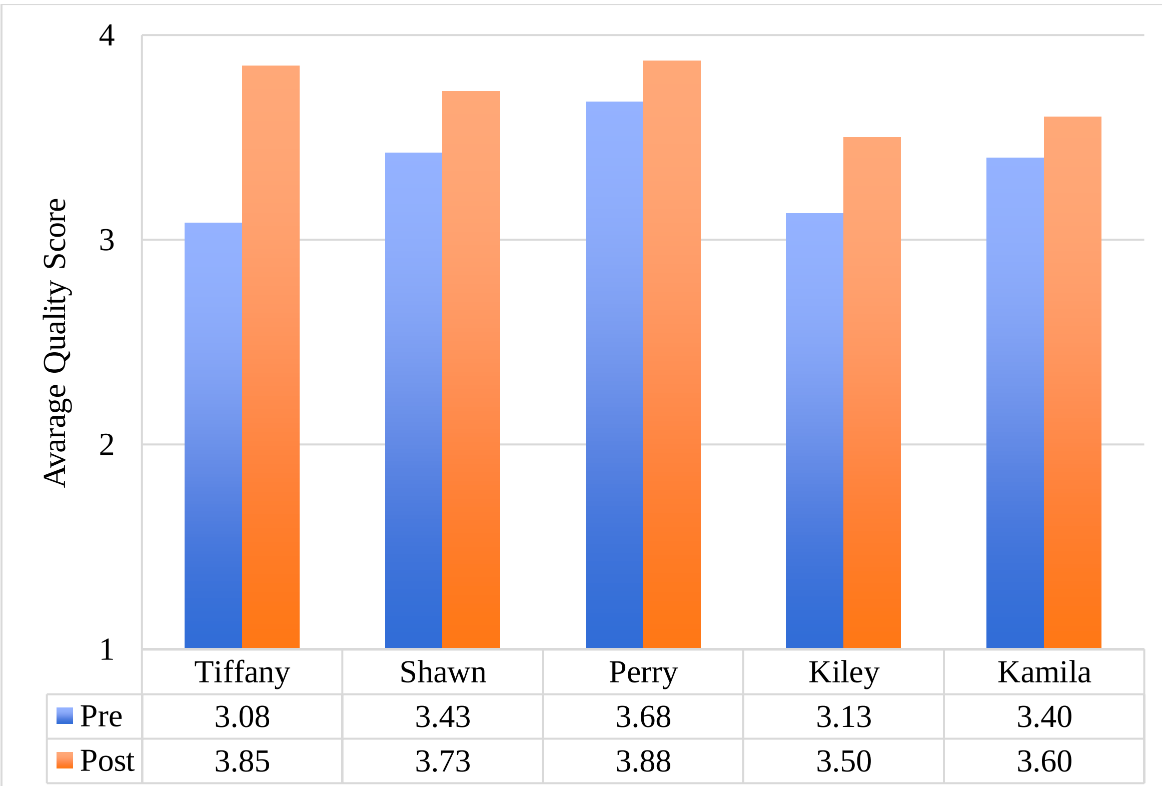
Tactile Graphic Quality Evaluation

The participants evaluated the quality of their initial creations as well as those of other participants. The researcher provided an evaluation rubric adapted from the standards and guidelines, which is a tool to determine if a visual illustration converted into a tactile graphic has tactual clarity and discrimination for visual information access. Based on the evaluation scores and peer comments, the participants revised their drafts and confirmed the ready-to-distribute versions for their students.

The average scores of the two quality evaluations (N = 5) were 3.34 (SD = 0.45) and 3.71 (SD = 0.31) out of five. Due to the small sample size, it was difficult to determine a statistically significant difference, but the data showed that all the participants' tactile graphics showed an improved quality over the participation. The items of "two-cell labeling" and "brailling" were rated the highest at 3.87 and 3.78 respectively, whereas "simplification" and "use of patterns" showed the lowest scores, 3.08 and 2.94. Over the revision process, the three items showed improvements of the three items with the highest score differences when compared to their pre-test scores: simplification (0.72-point difference), use of patterns (0.51-point difference), and tactile integrity (0.56-point difference). Tiffany's average scores individually showed the highest improvement (0.77 points) compared to the average score difference (0.38 points) as she resolved the issues of tactile integrity and minimum spacing between tactile elements. Perry and Kamila's scores showed only a 0.20 increase as they made minor revisions based on their peers' feedback and suggestions. Details of each quality item's score difference in the peer evaluation are in Figure 16.

Figure 16

Quality Scores Difference of Peer-evaluation



The participants could identify room for improvement through the evaluation session as well as provide concrete and specific criterion-based feedback. The post-test scores' average standard deviation (SD=0.31) increased from the pre-test's (SD=0.45). The participants considered meeting all the rubric items consistently instead of missing items after revising their drafts. Specifically, on the two items "Simplification" and "Use of Patterns," all the participants showed more progress than the other evaluation items. As described in the participants ' outcomes, those were the two main items considered when converting original graphics into tactile graphics to support students with VI to access the same level of information as sighted peers visually do. In contrast, the post-test scores related to braille showed the most minor difference compared to pre-test scores.

Qualitative Findings

Network Opportunities.

The learning community activities helped the participants connect to colleagues under shared goals and interests. The participants agreed that the activities provided connections to other colleagues who served students with VI who needed to access visual-intensive academic areas using math and science tactile graphics. As itinerant teachers, Tiffany and Perry reflected that the activities expanded their connections to colleagues interested in tactile graphics. They sometimes felt isolated when working in itinerant settings unless they actively sought out connections. Few opportunities for professional development existed for them at the school district level. The following are excerpts from a conversation between the two participants:

> *"Because we worked in other places where we've had to be collaborative, we tend to gravitate towards that, so it's a struggle. The back and forth, and the feedback, and it's essential for anything… Now I'm just out there by myself ands it's difficult sometimes so there's a real plus in that connecting… You gave us an opportunity to explore something that we're passionate about and something that we want to improve ourselves and our output on." (Tiffany)*

"I've learned so much from you… We have a lot of similarities, and that's been great that we are working with these academic kids, but I also appreciated that opportunity to collaborate with the others because they brought other ideas to the table… Great, I've really been able to take so much away from it, just ideas or thinking or like I feel like. A lot of my personal colleagues have been doing this, so long that they don't think out of the box." (Perry)

Kamila and Kiley articulated that they learned from the teachers who were highly-experienced in teaching students with VI during the participation. Kamila considered herself an entry-level TVI with relatively fewer teaching years, and Kiley referred to herself as a newbie utilizing technology to create tactile graphics. They pointed out how their connections to experienced colleagues benefitted them during the community activities. They shared:

"I think I might have been the newest TVI. I felt very much like a mentee role with a peer, and I felt like she (Perry) was able to pass on her knowledge… I could bring up a problem I had, and then I was able to get that more experienced feedback, which was really nice. I think she had a wealth of knowledge of resources I didn't even know about she was able to talk about and give ideas or materials for, that was excellent. There are just a lot of different layers of experience in this, and so it was really for me beneficial to like to get that knowledge passed down…" (Kamila)

"I was excited to check out some of those computer-based programs that people had mentioned, and I think every single one I looked up I couldn't access on my work

computer because I had to download something or it was blocked, and then it's like all proper well. I guess I can't do that one…It's like that's one more step and it makes it more difficult and not necessarily as easy as just checking out this new thing." (Kiley)

Peer-supported Learning.

In addition, the community activities provided TVIs with opportunities to learn from peers and gain resources. Participants agreed that support provided by peers enabled them to learn throughout all creation steps from planning to revising. The activities enriched interactions, which led to sharing ideas and resources related to creating tactile graphics. The participants highlighted the support from peers throughout the activities. The participants stated as follows:

"As much as I would love to take a class on this, I wish there was more to do, more to learn places to get that information. This was really good for me in that regard, I don't have a lot of time, so this was really an awesome thing for me." (Tiffany)

"In collaboration, we're able to have like these other ideas of ways that I can better meet my students in the visual needs… These activities have just really opened my eyes to like a just a more flexible way of thinking, and I loved listening to some of the ideas… So, I really think its collaborating opportunity is another resource…" (Perry)

"Hearing and seeing different people's ideas and seeing how that might apply to my students are talking through some potential errors so that group brainstorming was really helpful for me." (Kiley)

Further, the tactile graphic creations served as resources even if the participants were not currently using the ideas or did not have experience with peers' approaches. The researcher captured a discrepancy in attitudes on the two types of resources, peer-created versus existing source files and commercial kits. While the participants did not recognize source files and commercial kits as highly relevant resources in their practice, they were open-minded about employing their peers 'ideas and creative methods, as several participants articulated:

> *"It's really important for all of us to share that information, so I just really appreciate this class and learning and gathering because every time I learned something new, it's not only something I can share. It's something I can put in my personas repository to pull out later and say what I know will work really good there. So that's it, I had a little bit of education, but it's been more experience that's trial and error." (Tiffany)*

> *"Would say like the different resources that were provided were helpful in learning either like the step by step, to see how your own graphic is going, or you can also view other graphics that are well-made and interpreted have based on what those graphics have done ways that you can make your graphic easier to read." (Shawn)*

> *"But I love the fact that, even though this group was small, there was just so much sharing of resources, you know somebody just said, oh I got that on this. The graph*

vendors, or whatever I think we were talking about a couple of weeks ago about we didn't make them anymore." (Perry)

"I would say the experience of the other TVIs is helpful … Here people have experience and have used some of those strategies or some of the other machines and hearing how they worked well for them or didn't work well for them was helpful." (Kiley)

Learning Practices.

One interesting point was that the participants wanted to learn creative ways to develop tactile graphics. Participants who had relatively more teaching experience felt familiar with commercial and standard-type tactile graphics, so they wanted to learn from and practice other colleagues' creative ideas and resources beyond the examples that guidelines and standards showed. They said:

"Yes, we learned the BANA guidelines, yes, we learned the technical side, but not the creative side, and it would have been very helpful, had we had more time to explore maybe had another project or two. So that was my experience in my education." (Tiffany)

"And I've been lucky to work with some people who are very creative. And have made things and then brought them in when they were done and left them like on our shelf in case somebody else could use it, like somebody that maybe did the bones using like toothpicks or something… It's been the exchange of ideas and creativity. I love the fact that you said you use your cricket I have a cricket maybe every TVI program should

have you know cricket… OK, maybe it's not you know the documented text, but in this field, I think we have to learn from each other." (Perry)

Another takeaway for the participants was that the community activities supported TVIs in problem-solving while creating tactile graphics collaboratively. In addition to employing decision-making tools, the participants reflected that peer involvement helped resolve issues throughout their creation process. The meetings provided opportunities to share problems and questions at each creation step.

"It was nice to be able to like talk through the different choices and just problems all different or even discuss different issues and how things are in different settings in different states, I think that was interesting the list of resources is great to have even if I don't necessarily have time to go through it all right now." (Kiley)

"Yes, it was helpful to talk through the graphic planning from the beginning stages with somebody else and get their ideas and perspectives on how to do it." (Shawn)

"For me, it was that it was like the peer-to-peer involvement. I was explaining my graphic to the peers talking through it, I think it was in that talking through it, that night with Shawn that. I was able to start, what I don't really like or I'm not only able to explain this fully because there's something missing, and that was one of the strongest meetings most impacted on me." (Perry)

"I learned a lot from talking with a peer and just discussing ideas and narrowing down where we might have problem areas, rather than step by step; this is how you make it." (Kamila)

Summary

This study investigated TVIs' experiences of learning community activities for creating tactile graphics. This chapter presented the findings of the data collection and analysis findings to answer this study's three research questions. To collect and analyze the data, the researcher employed mixed methods to explore how TVIs' community activities supported knowledge and skill development, utilization of tools, and professional development related to creating tactile graphics. The quantitative results found that the community activities improved the participants' average self-rated competency scores. Even though each participant showed varied scores across the evaluation items, the findings showed that the participants who interacted with TVI colleagues and experienced a systemized creation procedure showed improved knowledge and skill development aligned with the enhanced quality of their tactile graphics. Throughout the interviews, the TVI participants in this study agreed that the community activities supported knowledge and skill development, utilization of tools, and collective learning outcomes. Through the data analysis, several themes were captured from the interview transcripts and provided insightful findings related to the practice of creating tactile graphics. In the next chapter, the researcher will delineate a discussion of key findings in this chapter, implications for future research and practice, limitations, and conclusions.

CHAPTER 5: DISCUSSION

This study aimed to investigate the learning community experiences of TVIs related to their development of knowledge and skills, use of tools, and community participation in creating tactile graphics. Knowledge and skills for creating tactile graphics are essential for TVIs' professional development. Learning opportunities such as conferences, workshops, and online resources have been established to develop specific skills and knowledge areas for pre- and in-service TVIs. However, few studies have examined TVIs' experiences in a community where they learn the whole procedure of tactile graphic creation using different planning and evaluation tools. Based on the results of Chapter 4, this chapter discusses the findings of this study, limitations, implications for future practice and research, and a conclusion.

Research question 1: What are TVI's experiences of community activities related to skill development in creation of tactile graphics?

Adapting visual-intensive materials is an essential professional skill for TVIs in school settings. Since many visual-intensive materials are used in school settings, transforming printed graphic forms into accessible media is necessary for students with VI to access academic learning like their peers without disabilities (Bischop, 2010; Spungin et al., 2007). Creating tactile graphics is not merely converting graphical materials into a tactile form but also ensuring simplification and tactile clarity while conveying the essential information that visual representations include (Jaquiss, 2010).

The participants in this study showed an increase in average competency scores. The pre- and post-test evaluations showed positive learning outcomes on the competency items. One interesting point is that the standard deviation scores of all participants decreased over the duration of their participation. This result can be interpreted as that individuals' scores on the competency items became closer to the average scores for all participants. The low difference in standard deviation scores can be interpreted as their scores spreading out. As indexed by the participants' scores, the community activities supported participants in becoming more aware of the tactile graphic creation process. This result supported the previous studies' findings that highlighted that a systemized creation process, from planning to revising, can contribute to producing high-quality tactile graphics (Rosenblum et al., 2021; Steele, 2015).

In addition, score increases existed on all the items ranging from 0.4 to 2.4 points, aligned with improved quality scores through the participants' revisions. Specifically, the "use of checklist" item showed the highest score increase (a 2.5-point difference). In the early phase of this study, participants were less aware of the editing process when compared to knowledge and skills based on basic rules of guidelines and standards. TVIs would create tactile graphics on the fly and individually before participating in this study, thus they were less aware of the editing process using specific evaluation criteria. The participants' reflections additionally support the score increase that the evaluation rubric helped them improve and control the quality of their tactile graphics. The experience of using a checklist as part of the creation process appeared to increase their sense of competency and knowledge of the process, according to a decline in the standard deviation scores.

Lastly, the researcher found a score decrease on Shawn's competency test items related to technology use throughout participation in the activities. The drops showed discrepancies between competency and tactile graphic quality scores. His average quality scores increased over the period of the study. He learned to create tactile graphics using computerized methods, including hardware/software, and was expected to show meaningful learning outcomes related to the items. In the interview sessions, he shared learning outcomes in differentiating textures and maintaining minimum space between tactile elements while using his computerized creation methods. Within this study, the researcher cannot determine what factors affected the decrease in scores, but it may have resulted from other external variables (e.g., misunderstanding of the evaluation criteria, underconfidence, or bias). Specifically, the competency tests relied on the self-ratings of each participant; therefore, his scores may reflect personal preference regarding his level of competency in each test (Yannakakis & Hallam, 2011).

In addition to findings in competency score changes, the qualitative results of this study support that the community activities led the TVI participants to achieve the learning outcomes of knowledge and skill development. In particular, the participants agreed that the community activities increased their awareness of the systemized creation process, including planning and revision per the recommendations of guidelines and standards. The participants had already learned knowledge and skills for creating tactile graphics through the TVI preparation programs, according to the CEC standards' skillset related to converting printed materials into tactile forms to access math and science learning (Council for Exceptional Children Division on Visual Impairments and Deafblindness, 2018). In addition to the formal training experience, this study's activities reminded participants about the systemized creation procedure as the guidelines and standards specified for each creation step. Most TVIs only started teaching after receiving basic training in tactile graphic creation in university TVI programs. However, their knowledge and skills varied depending on in-service training experiences, years of certification, and individual interest in tactile graphics (Rosenblum et al., 2021). Also, in-service training opportunities specialized in math and science tactile graphics have not been offered frequently to the whole TVI population in practice (Pogrund & Wibbenmeyer, 2008).

In particular, the participants reflected that their previous creations in practice needed to be scaled down due to a lack of preparation time and the need to fulfill last-minute requests from students and classroom teachers. They would skip some steps or speed through them to save time instead of following the procedure they experienced in the community activities. The difficulties were observed by limited creation time even though TVIs have knowledge and skills in creating high-quality tactile graphics. The participants shared that it was beneficial for them to experience step-by-step procedures to expedite the creation procedure in school settings through the activities which determine the quality of service delivery for students with VI (Kahn & Lewis, 2014).

In the interview sessions, ensuring crucial elements for high-quality tactile graphics was captured as one of the benefits of the community activities. The researcher introduced guidelines/standards, planning sheets, and an evaluation rubric to help consider essential components for high-quality tactile graphics through the activities. For example, the participants considered sizing to fit their drafts to their students' tactile skills. Kamila resized the original graphic to three square inches because her student had additional disabilities besides VI. Sizing is an essential factor that affects the recognition of tactile images, as over-or under-sized tactile diagrams make accurate identification difficult even in a high-resolution (Gong et al., 2020; Wijntjes et al., 2008). Also, Shawn and Perry employed braille keys to indicate the elements of animal cells and rays of tactile angles. The keys helped students with VI identify appropriate information about animal cell elements and angles with two rays. The findings showed that the participants learned to recognize the specific component items and complete all the steps throughout the creation experience, which was aligned with (Lawrence & Lobben, 2011)'s findings that well-determined tactile symbols assist understanding by displaying meaningful information in a structured manner.

Regarding the use of colors, Tiffany, Shawn, and Kiley voluntarily used colors in their tactile graphics. Many students with VI who use tactile graphics still have low vision (Corn & Lusk, 2010). As Perry shared, keys and symbols are sometimes ignored when creating tactile graphics because the elements may look like a tiny part of the creation. However, the guidelines and standards specify clear rules for including keys and symbols to present the original graphic's essential information (Braille Authority of North America, 2010). Wright (2008) recommended using materials with bright colors, high contrast, and solid backgrounds. Also, Ramsamy-Iranah et al. (2016) argued that color increases students' recognition time when reading tactile symbols. Thus, the use of colors should be considered when creating tactile graphics based on adaptations for students with low vision, such as providing high contrast colors, avoiding combinations of dark colors, and highlighting border lines.

Lastly, the community activities increased the participants' productivity in creating tactile graphics in schools. TVIs need to maintain productivity in school settings because many existing studies have reported that they often lack time to develop high-quality tactile graphics (Rosenblum & Herzberg, 2011). Even though the participants recognized the merits of the step-by-step planning and revision process, they preferred to scale down the creation process in school settings because the guidelines and standards were considered too theoretical and complicated. The need to balance productivity and quality aligns with the previous study findings regarding challenges in creating tactile graphics in schools (Aldrich & Sheppard, 2001; Phutane et al., 2022). Limited time for producing tactile graphics inevitably led TVIs to skip essential steps of the whole procedure or only complete them partially. Creation work may take multiple days, and the need to create on-the-fly materials forces TVIs to skip essential steps, such as proofreading, affecting final product quality.

Nevertheless, the community activities provided a straightforward creation procedure with concrete steps that TVIs can apply in school settings. The activities contributed to learning concrete creation steps for high-quality tactile graphics and techniques that balance time and workload. The learning experiences helped TVIs internalize the creation process, reducing the need to read and apply every guideline and standard item and thus speeding up their creation time.

Based on the findings, the researcher recommends developing and facilitating community-oriented learning modules for advanced professional knowledge and skills in creating tactile graphics as part of TVIs' professional development. Existing training and professional learning modules focus on knowledge and skills to simplify graphic images into adapted tactile graphics or use specific creation tools. In addition, integrated professional learning opportunities with community aspects are needed to help TVIs experience a systemic creation process by communicating with other TVI colleagues with diverse experiences and resources. For example, regular professional development sessions using online conference platforms can enrich community aspects for developing knowledge and skills in creating tactile graphics. An online discussion group can serve as a resource archive that includes guidelines, sample images, and exemplary case studies conducted by other TVI colleagues in school settings.

Research question 2: What are TVI's experiences of community activities regarding utilizing different tools for creating tactile graphics?

A systemized creation procedure needs various tools to create high-quality tactile graphics representing the same level of information the original graphics intended to deliver. In this study, the participants experienced different tools for planning and evaluation. Through pair or small-group activities, the participants had the opportunity to practice the appropriate use of the tools. For example, the Decision Tree helped determine if the original graphics were meaningful in a tactile form rather than simply repeating information in texts. Some of the participants' original graphics were complicated and challenging to examine through touch due to overwrapped or unclear textures and lack of minimum spacing. The tree helped the participants choose meaningful graphics for tactile forms as well as control the quality of tactile graphics.

Based on the participant's tactile graphic creations, the researcher observed the benefits of employing the tools throughout the creation procedure. Using the planning sheets, each participant succeeded in clarifying essential considerations for high-quality tactile graphics. The participants determined what information should be conveyed according to the purpose of the original graphics and then considered simplification and elimination. Busy graphics or visualized data (e.g., tables, charts, and graphs) needed concrete ideas. Simplification of complex visual representations and elimination of unnecessary information was primarily considered in the planning activity. The planning sheet required the participants to specify the types of textured lines, areas, and points for tactile representations they planned to use. For example, the planning sheet guided the participants to consider the minimum number of textures to ensure tactile clarity and discrimination. This process helped ensure that the participants' drafts would be easily distinguished through touch. In addition, the rubric helped clarify the essential items to consider for high-quality tactile graphics and their peers' performance. The participants provided meaningful expectations for improvement based on concrete criterion items. The participants left comments and feedback for improvement based on concrete criterion items. The participants left comments and suggestions to help their peers identify potential considerations in the revision process, thus improving the quality of the drafts.

In the interview sessions, the participants expressed contrasting perspectives on the usability of source files in school settings. Previous studies showed that tactile graphic source files had high potential as valuable resources. Park and Hong (2022) found that existing source files were expected to save time and effort in creating tactile graphics. Spungin et al. (2007) also pointed out that tactile image sources can effectively help TVIs balance time and quality practice. However, the participants in this study did not prefer to use sample source files as well as recognize the existing files as highly valuable resources.

In the interviews, the participants reflected concerns about finding appropriate source files and braille translation issues between UEB and Nemeth. Different notations are used depending on the state. Only 70 percent of teenagers who use braille for literacy are introduced to Nemeth (Bell & Silverman, 2019). If a math source file only provides one math notation, TVIs need to add the other format as well (Knowlton & Wetzel, 2006). The emerging themes in this study show meaningful considerations for online source file repositories. To improve usability, it is recommended that the source-file repositories provide more flexible options for editing features and braille notation to resolve the practical issues noted by the TVI participants. In addition to sharing downloadable, ready-to-print tactile images, the providers can include manual input features for TVIs to edit and modify braille and tactile images, encouraging TVIs to use the sources flexibly according to their needs and students' academic levels. These changes will make the source files a more valuable and practical open source.

In addition, compatibility issues emerged in the interview sessions for hardware and software used for creating tactile graphics in practice. The participants agreed that computer-assisted options could provide more options for tactile graphics as well as benefits for overcoming the limited amount of creation time in school settings. However, some source files are only editable using specific hardware/software. Previous studies have recognized school districts' hardware and software availability and support as an essential factor affecting TVIs' technology use (Zhou et al., 2012). In this study, the compatibility issues related to hardware and software were identified by the itinerant TVIs serving multiple students with VI in various locations across the school district, which caused time limitations and access to tactile graphic machines only available at specific schools or regional resource center. Also, the participants in special school settings were not accessible to particular types of source files because their schools did not purchase compatible hardware. To resolve these issues, it is recommended for source file providers to consider using more flexible formats that work universally with hardware and software options that TVIs can easily access, such as braille embossers and APH-manufactured tactile graphic machines (e.g., PixBlaster). Establishing a regional center where an array of equipment is sharable for TVIs for more computer-assisted creation methods. The center also can function as a community base to support TVIs to build and develop the network of human resources.

Research question 3: What are TVI's experiences in participating in a community when creating tactile graphics?

Connections to other TVI colleagues provided opportunities to learn with colleagues pursuing shared goals and interests in creating tactile graphics. Through the community activities, the participants learned from peers and resources shared as well as received peer support for solving problems while creating tactile graphics in practice. The collaborative work led to high-quality tactile graphics as well as the development of knowledge and skills in creating tactile graphics. This study's quality evaluation scores showed that the TVI participants progressed through the peer-evaluation phase by revising their draft tactile graphics based on other participants' suggestions and peer evaluation.

This study found that the connections benefited the two groups of participants, itinerant and entry-level teachers. Tiffany and Perry, the itinerant teachers, showed meaningful learning outcomes of competency development and improved quality of tactile graphics through the community activities. They shared the excessive workload and lack of support in itinerant settings described by existing studies (Brown & Beamish, 2012; Morash & Siu, 2016). This study's activities offered opportunities for itinerant teachers to interact with other TVI colleagues with diverse backgrounds and teaching experiences. The community activities functioned as engaging them to collectively brainstorm ideas, share resources, and exchange feedback and ideas for improvement.

Also, Kiley and Kamila, the two entry-level TVIs, benefited from the community activities as they learned from TVIs who were more experienced in creating their tactile graphics. Suggestions and feedback from experienced teachers contributed to their tactile graphics' quality, specifically in terms of using technology and gaining insightful ideas.

Connections between professionals have been recognized as essential for developing professional expertise in serving students with VI (Lewis & McKenzie, 2009; Nashleanas, 2021; Wong & Cohen, 2015). The community activities provided a systematic way for TVI colleagues to share relevant information throughout the creation process.

Additionally, the community activities in this study provided TVI participants with collaborative learning opportunities from peers at each creation step. The TVI participants recognized their colleagues' experience and knowledge as creative resources. In addition to the resources and example images the researcher provided, participants shared ideas and reflections on different creative ways of creating tactile graphics. Those interactions in the context of a systematic creation process enriched more active reflections and feedback than lecture-style workshops and presentations (Lewis & McKenzie, 2009). In contrast to their lack of interest in online pre-made tactile images, the participants highly valued their colleagues' ideas and creations as creative teaching resources. Participants' learning outcomes support future professional development for TVIs based on active learning, reflection, and feedback with high involvement (Ely & Ostrosky, 2017). The community aspects, including TVIs' diversity and creativity in practice, need to be integrated into university programs and in-service programs for TVIs' professional development in creating tactile graphics.

Lastly, the participants collectively handled the decision-making situations while creating high-quality tactile graphics through virtual meetings and communication methods. The online meetings and communication eliminated geographical barriers as well as allowed participants to bring their issues or concerns to their colleagues and discuss possible options for problem-solving. The collaborative process involving posing and solving problems continued to develop professional expertise in planning and editing tactile graphics, supported by the recent study findings on how teacher communities contribute to solving problems in school practice (Bannister, 2015). The characteristics of individual students with VI vary (e.g., level of tactile perception, previous experience in using tactile graphics, and understanding of tactile keys/symbols). Since learning practice might be insufficient in college programs, ongoing in-service professional communities are necessary for TVIs to learn how to create tactile graphics by sharing ideas and exemplary experiences based on the main principles set out in guidelines and standards.

Limitations

This study has several limitations. This study's findings may not generalize to all TVIs due to the small number of participants. The experiences and learning outcomes of the participants do not represent all TVIs' learning outcomes. Before participating in the study, the participants may have had relatively higher interest and competency in creating tactile graphics than the other TVIs. The higher interest of the participants may have affected the score differences in their competency ratings and quality evaluation. Also, several challenges were captured when sharing the experiences in utilizing computerized creation methods for tactile graphics, however, the perspectives narrated by the participants may differ from those of TVIs who did not participate in this study or have high competency and experience in technology use.

In addition, the researcher used self-reported data to investigate participants' knowledge and skill development instead of developing an evaluation tool with high validity and reliability. The self-reported evaluation scores are based on each participant's ratings, which the scores may have a bias or not represent a correct level of performance measurable using standardized criteria. Further studies are needed to evaluate knowledge and skills in creating tactile graphics without impacts from internal and external factors that may affect measure competency scores accurately.

Lastly, this study's activities were facilitated using a fully online modality due to the outbreak of the COVID-19 pandemic therefore implementing the community activities with more extended interaction in different settings (e.g., in-person, hybrid, or different levels of virtual interaction) may yield different results. This study's findings showed how community activities led to improving knowledge and skills in creating tactile graphics as well as connecting TVI colleagues with shared interests and goals utilizing a virtual learning modality. The findings in this study regarding interactions and communication of the participants in online settings cannot be generalized to other learning environments.

Implications

Despite the limitations, this study contributes to expanding knowledge of the lived experiences of TVIs in creating tactile graphics through the learning community activities. Based on the findings of this study, the researcher suggests the following implications for future practice and research. First, this study developed and implemented a learning-community-oriented approach for supporting TVIs to develop professional knowledge and skills in creating tactile graphics. Beyond tactile graphic, the approach and activities can be applied to other expertise of TVIs for quality special education services for the learning success of students with VI in school settings.

Second, this research found the benefits of systemized creation procedure for high-quality tactile graphics. The activities implemented in this study can be applied to diverse settings and groups of professionals serving students with VI in and out of school settings. The researcher only facilitated the activities entirely online due to the COVID-19 pandemic using teleconferencing and online communication tools. The pandemic led TVIs to commit to special education service delivery in virtual settings. The activities have the potential to implement in various settings, including in-person, hybrid, and asynchronous. Based on TVIs' proficiency in technology, it is recommended to conduct more studies regarding different learning platforms and tools to provide TVIs with multiple layers of professional development.

Lastly, this study identified potential issues for improving source files and online resources. The participants reflected on several issues related to braille notation, additional editing for adaptation, and hardware/software compatibility. The findings showed a contrasting perspective on using source files from the previous study findings. Multiple braille notation options of UEB and Nemeth and flexible editing can enhance TVIs' usability of online source files and resources.

Conclusions

Learning in communities is essential for TVIs when pursuing professional development in practice. Adapting visual-intensive graphic information needs professional knowledge and skills of TVIs to support students with VI in school settings, primarily by eliminating barriers to accessing the same information their sighted peers use. In this study, the researcher developed and provided a community experience for TVI participants in which they learned to plan and create high-quality tactile graphics. The participants experienced a concrete creation process based on the recommendations of guidelines/standards. They utilized various tools to convert visual representations into tactile graphics with tactile clarity for students with VI. Based on the data collection and analysis, the researcher found that the community activities positively contributed to the development of knowledge and skills associated with the creation process and provided a meaningful opportunity for TVIs to interact with colleagues regarding resources, decision making, and problem-solving.

Even though this study has several limitations, this study contributes to developing a comprehensive activity package that allows TVIs to experience a systematic process for creating tactile graphics and expands the scope of knowledge of the lived experiences of TVIs regarding participating in community activities. This study indicates that TVI community activities supported the development of knowledge and skills, including awareness of the systemized creation procedure, consideration of essential components, and increased productivity in practice. Planning and evaluation tools supported TVIs to consider creating high-quality tactile graphics. Also, the community activities provided connections and interactions between colleagues with various degrees of experience and backgrounds, which allowed TVIs to learn from peers and gain resources for creating high-quality tactile graphics.

Learning to create tactile graphics is part of every TVIs ’professional learning in practice based on connections and interactions with colleagues with shared goals and similar issues. The TVI community deserves to be a significant resource for tactile graphics. It can potentially support other skills that promote the academic success and inclusive learning of students with VI in school settings. This study’s findings will improve in-service professional development opportunities and the conventional training that TVIs pursue.

Appendices

Appendix A. Social Media Recruitment Post Prompt

Hello Colleagues,

My name is Jinseok Park, and I am a doctoral candidate in the Department of Disability and Psychoeducational Studies at the University of Arizona. Dr. Sunggye Hong, my academic advisor, and I are recruiting certified Teachers of students with Visual Impairments (TVIs) for my dissertation study on investigating the experiences in a TVI community for creating tactile graphics in math and science.

Eligible TVI participants must: 1) be math/science teachers in schools for the blind or itinerant teachers working with students with VI, 2) have more than middle and high school student(s) with VI who receive special education services and needs tactile graphics for math and science learning, and 3) be able to participate in this study online using emails, virtual meetings, and electronic discussion groups. Age, gender, and ethnicity data may be collected as documenting demographics; however, this study will not use these characteristics as variables.

If you participate in this study, you will be able to create up to two sets of tactile graphics for your student(s) who need tactile graphics for math and science learning. You will brainstorm various ideas on creating high-quality tactile graphics with other participants. As a principal investigator of this study, I will support you by providing resources and hardware/software assistance for developing your knowledge and skills in creating tactile graphics. You will be asked to participate in the following activities:

1. 5 Online meetings via Zoom to brainstorm ideas and share resources for tactile graphics (5 hours)
2. Creation of up to two sets of math and science tactile graphics (may vary)
3. Self- and peer-evaluation of your graphics quality using a rubric (1 hour)
4. Revisions of your tactile graphics based on the evaluation results (may vary)
5. 2 online interviews via Zoom to share your participation experiences (2 hours)
6. Documentation of a comprehensive post about your tactile graphics (1 hour)

There will be no monetary or direct compensation for your participation. However, as an appreciation for the time and effort to participate in the study, you will receive a $100 merchant gift card if you complete participating until the study ends.

If you and your student are interested in participating in this study, please contact Jinseok Park at jinseokpark@email.arizona.edu or send me a text at (520) 328-7649 to discuss more details. For sign-up, an electronic consent form will be electronically delivered. You can check out the activities' details in the following:
https://uarizona.co1.qualtrics.com/jfe/form/SV_cvjmAm9WuLfIHhc

The Institutional Review Board of Human Subjects Research at The University of Arizona reviewed and approved this study project, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of research participants.

Jinseok Park
Doctoral Candidate
Department of Psychoeducational and Disability Studies
University of Arizona

Appendix B. Teacher Consent Form

University of Arizona
Consent to Participate in Research

Study Title: A Study on Investigating the Professional Community Experiences of Teachers of Students with Visual Impairments in Creating Math and Science Tactile Graphics

Principal Investigator: Jinseok Park

You are being asked to participate in a research study. This document contains essential information about the research and what to expect if you decide to participate voluntarily. Please consider the information carefully and feel free to ask questions before making your decision on participation.

Purpose of the Study
This study investigates the professional community experiences of teachers of students with visual impairments in creating math and science tactile graphics. I hope you will create math and science tactile graphics with other colleagues and develop relevant professional knowledge and skills in tactile graphics for your student(s) who use a sense of touch as a primary learning medium.

Withdrawal from the Study
There is no risk or penalty for withdrawing from the study. You can stop at any time by simply informing researchers to opt-out, and we will make sure to store any documents that have been received securely. The data will be coded anonymously protected. If you wish to opt out, you will retain the work completed throughout your participation. Your decision will not affect any future relationship with The University of Arizona.

Commitment Details
If you participate in this study, you will brainstorm and create with other participants up to 2 sets of tactile graphics for your students who need tactile graphics for math and science learning. As a principal investigator of this study, I will support you by providing resources and hardware/software assistance. You will be asked to participate in the following activities:

7. 5 Online meetings via Zoom to brainstorm ideas and share resources for tactile graphics (5 hours)
8. Creation of up to two sets of math and science tactile graphics (may vary)
9. Self- and peer-evaluation of your graphics quality using a rubric (1 hour)
10. Revisions of your tactile graphics based on the evaluation results (may vary)
11. 2 online interviews via Zoom to share your participation experiences (2 hours)
12. Documentation of a comprehensive post about your tactile graphics (1 hour)

Compensation
I would appreciate your time and effort in participation, so you will receive a $100 merchant gift card if you complete all the commitments mentioned above.

Privacy/Personal Information Protection
There will be no collection of personal information unrelated to the purpose of the study. The research procedure also guarantees the privacy protection of participants. Your responses will be assigned a code number. The list connecting your name to this code will be kept in an encrypted and password-protected file. With your permission, I would like to record the Zoom interview and transcribe it. Your name will not be in the transcript or my notes. When the study ends, all personal information will be destroyed.

In addition, you will not be identified in any report or publication of this study. I will guarantee to protect your privacy in this study; however, each participant is not required to follow the same confidentiality standards.

Data Access
Jinseok Park, the principal investigator, will retain the participants' codes stored in Box cloud folders provided by the University of Arizona. The Box folder will securely store the data collected in this research. Only the principal investigator will have access to the confidential records.

The information that you provide in the study will be managed confidentially. However, there may be circumstances where this information must be released or shared as required by law. The University of Arizona Institutional Review Board may review the research records for monitoring purposes.

For questions, concerns, or complaints about the study, you may contact Jinseok Park at jinseokpark@email.arizona.edu or (520) 328-7649.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone not belonging to as a part of the research team, you may contact the Human Subjects Protection Program at 520-626-6721 or online at http://rgw.arizona.edu/compliance/human-subjects-protection-program.

Signing the Consent Form

I have read (or someone has read to me) this form, and I am aware that I am being asked to participate in a research study. I have had the opportunity to ask questions and have had them answered to my satisfaction. I voluntarily agree to participate in this study.

I am not giving up any legal rights by signing this form. I will be given a copy of this form.

______________________	______________________	__________
Printed name of Participant	Signature of subject	Date

Appendix C. Demographic Survey Form

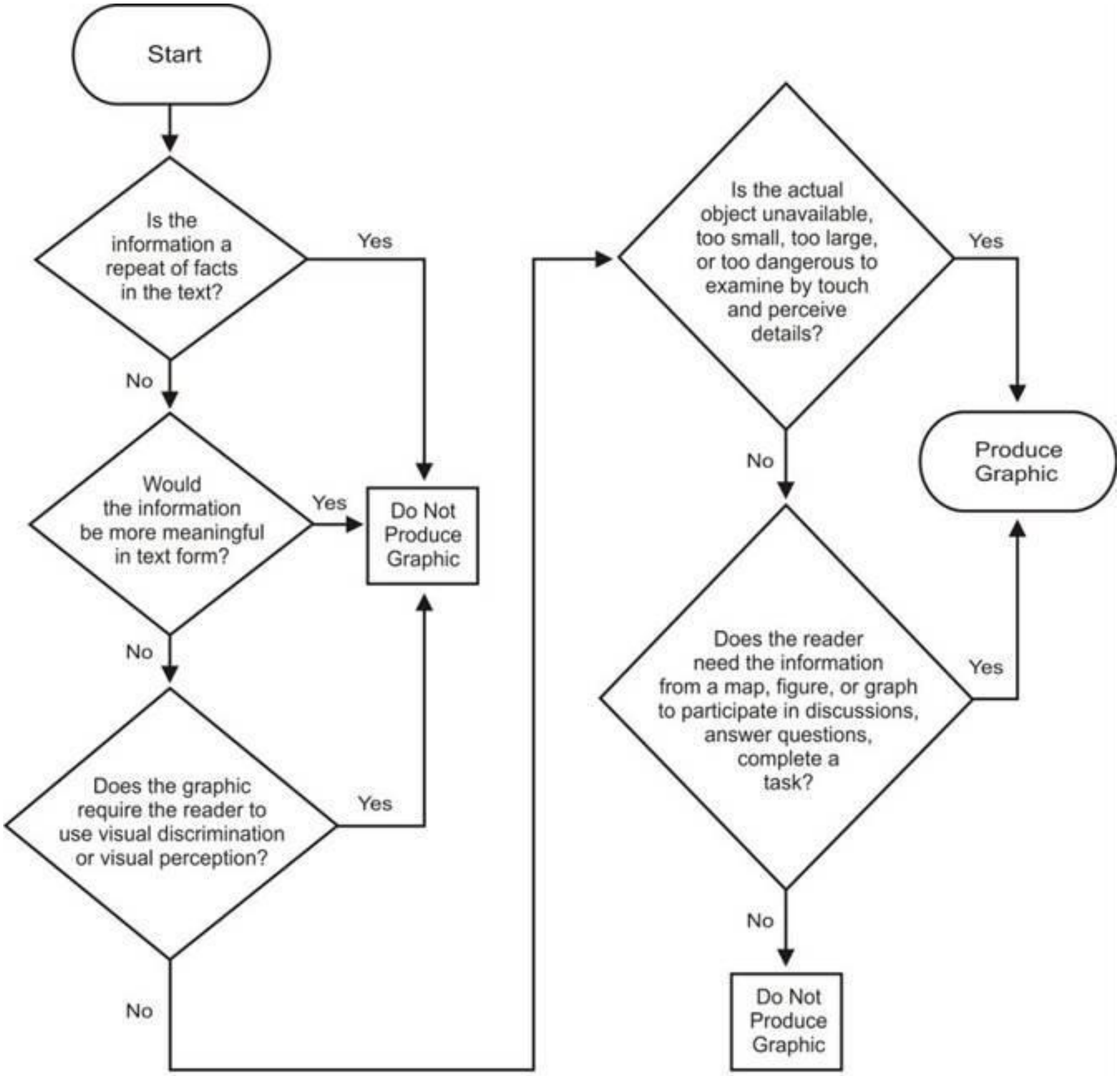
- Teacher name: ____
- Location: ____
- School District: ____
- Email address: ____
- Phone number (optional): ____
- Do you meet the following 3 items eligible to participate in the study?
  a. Are you a math/science teacher in schools for the blind or an itinerant teacher working with students with VI?
  b. Do you have a middle and high school student(s) with VI who use(s) sense of touch as a primary learning media and needs tactile graphics for math and science learning?
  c. Can you participate in this study fully online, using emails, virtual Zoom meetings, and discussion groups?

  Yes ________ No ________
- Why did you choose this student for this study?
  ____
  ____
- Can you share your student(s)' math/science goals and needs of tactile graphics?
  ____
  ____
- What specific area(s) are you interested in creating tactile graphics?
  ____
  ____
- What do you expect for groupwork with other TVI participants?
  ____
  ____

Appendix D. Self-reported Competency Evaluation Form

Item	Never tried	Poor	Fair	Good	Very good
1. Understandings of general guidelines for design of tactile graphics					
2. Making an area distinguishable from surrounding areas					
3. Using appropriate lines such as lead lines, arrows, and broken lines					
4. Using appropriate symbols (points and textures) when creating tactile graphics					
5. Using appropriate labels to identify an area, line, or point symbol					
6. Using distinguishable colors for students who have some visual acuity					
7. Considering on size of a graphic and paper according to the Guideline for Tactile Graphics					
8. Consideration of design techniques for transcribing complex diagrams such as simplification, elimination, separation					
9. Proofreading the graphics created by touch to verify the quality					
10. Using a checklist for making decisions about tactile graphics					
11. Operating more than one computer-related software					
12. Operating more than one hardware/software to produce tactile graphics					

Appendix E. Tactile Graphics Decision Tree



Appendix F. BANA Tactile Graphic Planning Sheet

PLANNING SHEET

Title:
Page:
Figure #:

1. What information should be conveyed?
    a. Read the surrounding text, caption, and labels to determine the purpose of the print graphic.
    b. Read review questions at the end of chapter/unit.
    c. Include:

2. Decide how the illustration will be presented in braille:
    a. Description in transcriber's note
    b. Overview, layers, or sections
    c. Tactile graphic
    d. Not produced
    e. Description and tactile graphic

3. Simplify the drawing. Consider:
    a. Can any of the parts be eliminated and/or margins cropped in the tactile representation?
    b. Can some parts be consolidated and/or minimally distorted?
    c. Can some parts be described in a transcriber's note?
    d. Will the graphic be separated into more than one section?
    e. Does the graphic need to be enlarged?

4. Identify components to be included in the graphic.
    a. Will the print labels fit in the available space, or will a key be required?
    b. What keying technique will be used?

5. Which production method is most suited for this tactile graphic?

6. Possible modifications:

	Area	Line	Point
1			
2			
3			
Alphabetic			
1			
2			
3			
Numeric			
1			
2			
3			

Appendix G. Tactile Graphic Quality Evaluation Sheet

Evaluation Rubric

Item	Exemplary (4)	Proficient (3)	Developing (2)	Missing (1)
1. Simplification	Tactile elements are simple to tactually understand.	Tactile elements are simple with a few confusions.	Tactile elements are visually simply but complicate to figure out using a sense of touch.	Simplification is missing or tactile clutters exist.
Comments:				
2. Decluttering and spacing	No clutter exists with a clear spacing.	1-2 clutter(s) exist with a clear spacing.	3-4 clutters or unclear spacings exist.	No minimum distance at least 1/8 inch
Comments:				
3. Use texture sparingly and only to add information.	Uses below 4 textures	Uses below 4 textures with a redundancy exists.	Uses 5+ textures.	Too many textures for information.
Comments:				
4. Limit the lines, points, and symbols on a drawing to ones that can be easily identified one from another by touch.	Different patterns clearly exist for tactual difference.	Different patterns clearly exist but it needs a minor revision.	Different patterns exist but they are very similar so that is not easy to distinguish each other by touch.	Tactual differences are missing.
Comments:				

Item	Exemplary (4)	Proficient (3)	Developing (2)	Missing (1)
5. Use different tactile symbols for different types of information.	Different symbols exist with clarity.	Different symbols exist but minor revisions need.	Different symbols exist but they are not clearly identifiable.	No differences between the symbols.
Comments:				
6. Use keys or notes as alternatives.	Keys or notes are clear and concise to understand information.	Keys or notes are clear to understand information with lead lines and arrows.	Keys or notes are used but need to be clear and concise.	Multiple lead lines and arrows exist and challenge to discernible understanding.
Comments:				
7. Explain and define all graphic symbols, either on the same page, facing page, or special symbols page.	Corresponding information exist at appropriate locations, in logical order.	Corresponding information is explained but a few info needs a relocation in in logical order.	Some corresponding information is missing or located in a random order. Major revisions are needed.	No explanation and definition across the tactile graphic
Comments:				
8. Use Grade 2 braille contraction s with no errors.	Uses contracted braille with no errors.	Uses contracted braille with 1-2 error(s).	Uses contracted braille with 3+ errors OR Used uncontracted braille with no errors	Used uncontracted braille with multiple errors.
Comments:				

Item	Exemplary (4)	Proficient (3)	Developing (2)	Missing (1)
9. Use a two-cell braille symbol, instead of one-cell symbol for labels.	Used two-cell symbol(s).	N/A	N/A	Used non-two-cell symbol(s).
Comments:				
10. Do not break the integrity of a shape with a braille label.	Assured the clarity of discernible textures for shape(s) and braille, with no overwraps and 1/32-inch+ height.	Assured the textures with 1-2 overwraps to be spaced.	Assured the textures with 3+ overwraps to be spaced.	The labels overwrap with tactile shapes and needs a separation from each other.
Comments:				
Total	/ 10 = (average)			

Adapted from Creating Tactual Graphics for Students who are Blind or Visually Impaired. (2017). Retrieved February 22, 2021, from Teaching Students with Visual Impairments website: https://www.teachingvisuallyimpaired.com/tactile-graphics-guidelines.html

Appendix H. Interview Guiding Questions

Thank you so much for participating in the focus group interview sessions. For this focus-group interview, you will reflect on your experiences in our community activities and how your participation impacts the development of knowledge and skills in creating tactile graphics. You will also talk about the tools we utilized in the activities, such as guidelines and standards of tactile graphics, an evaluation rubric for improvements, and an online repository for dissemination. Please see the guiding questions below.

1. What are TVI's experiences regarding participating in activities related to skill development in creating tactile graphics?
    a. Let's talk about the start of the project. When we began the study, what specific skill(s) did you want to learn through the activities?
    b. What specific skill(s) did you develop through the activities?
    c. How has your participation in the community activities impacted knowledge and skills in creating tactile graphics?
    d. What specific activity did you find beneficial?
    e. So overall, how did your participation support you in acquiring specific skills?
    f. Can you share additional experiences or thoughts in the participation for the development of knowledge and skills in creating tactile graphics?

2. What are TVI's experiences regarding utilizing different tools for creating tactile graphics?
    a. What tools have you found most beneficial in your creation of tactile graphics in this study?
    b. Let’s talk about specific tools that you utilized for creating your tactile graphics.
    c. How helpful were the guidelines and standards for creating tactile graphics?
    d. How helpful were the evaluation rubrics for creating tactile graphics?
    e. How helpful were the hardware/software support for creating tactile graphics?
    f. How helpful were the pre-made tactile images in online repositories for creating your drafts?
    g. Can you share additional experience or thoughts in utilizing the tools for creating tactile graphics?

3. What are TVI's experiences in participating in a community when creating tactile graphics?
    a. Prior to starting the study, what kind of conversations did you want to talk about in the community activities? Did you have those conversations? Why or why not?
    b. Were there benefits to engaging in the activities? If so, how did the activities differ from your individual work? Describe your experiences in engaging in individual work to create tactile graphics.
    c. What were the collaborative benefits of joining the activities?
    d. Can you share your thoughts or experiences to improve the community experience for TVI’s professional development in creating tactile graphics?

e. What were your experiences using the tools in a virtual setting?

4. Follow-up
   a. Can you share your additional experiences or thoughts in the activities for creating tactile graphics?

Appendix I. Examples of Themes, Subthemes, Clusters, and Verbatim Codes

Theme	Subtheme	Clusters	Verbatim code
Knowledge and Skills	Creation procedure	Being aware of creation procedure	“Implemented the procedure more effectively” “Crossed all the points” “Brought what you learned” “Review procedures as to what makes the best possible” “Became more aware of what is the best practice”
	Component requirements	Ensuring essential components of tactile graphics	“Utilized different textures” “Used different tactile representations” “Rearranged items for spacing” “Realized condensed or not” “Reminded to simplify”
	Productivity	Increasing productivity in practice	“Wanted directions on how to be better at the last minute” “Brought resources in the image quickly” “Balancing act of time”
Utilizing Tools	Planning tools	Helping outline expectations	“Knew what's expected” “Followed a pre-made decision” “Thought about what’s going into this graphic” “Understood better things that can be improved” “Became cognitive of what you are doing” “Made more aware of, putting up on the bulletin board” “Gave a good outline”

	Evaluation tools	Helping determine if clearly designed with consistency.	“Made sure every step of creation” “Gave a sense of relief whenever we can't give out something 100%” “Using for a minute what’s the difference to balance” “Recognized missing parts” “Reviewing like a quick”
	Source files and commercially available kits	Existing braille translation issues	“Conversed from EBAB to UEB” “Have to edit Nemeth into UEB” “Need UEB, not Nemeth” “Can't Nemeth for UEB”
		Challenging to determining if appropriate to use.	“Hard to decide what images are a value” “Have hard time to evaluate tweaks” “Just create it from scratch instead”
		Providing irrelevant resources to the students’ academic needs.	“A standard for every kid” “Each state has its own curriculum” “They might be different based on experience and curriculum” “They are different than the parts of the book” “Too generic for a second grader, like preschools.” “They are too high concepts”
		Providing inflexible resources to modify or edit.	“They are whole-cell images.” “Standard base is a base to start with like a blueprint”
	Hardware and Software	Enhancing productivity when compatibility meets	“Making on-the-fly” “Bunch of graphics in a short amount of time” “Just translate copy braille texts from Duxbury right into Quicktac”
Community activities provide	Network opportunities	Itinerants: being connected to colleagues in isolated settings	“Challenges due to a lack of collaboration” “Having somebody to be connected”

	Entry-level TVIs: being connected to higher-experienced colleagues	“Learning from the experienced colleagues” “Learned from colleagues like mentors”
Peer support	Interacting to share ideas and resources	“Having more to learn places to get information” “Seeing different people's ideas and how that might apply to my students” “Sharing information, putting repository, experiencing trial and error” “Receiving different resources from peers “Experiencing other colleagues' experience”
Learning Practice	Learning creativity and problem-solving in practice	“Experiencing the creative side of colleagues” “Working with people with creativity” “Talking through the different choices and problems, discuss different issues in diverse settings” “Talking through the graphic planning from the beginning stage” “Getting involved in peer-to-peer interaction” “Discussing ideas and narrowing down where might have problem areas”

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