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Advancing Mathematics Education for Visually Impaired Students Through Geometry Tactile Diagrams

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Abstract: Mathematics is heavily reliant on diagrams and spatial representations, which can be challenging for blind and visually impaired (BVI) students. This study examined the role of geometry tactile diagrams (GTD) in supporting BVI students' learning. Twenty blind students from the Mathematics unit at the Authors' College, selected from a general studies course, were randomly assigned to a treatment group using GTD or a control group with standard instruction. Results showed that students taught with GTD made significantly greater progress than the control group (ES = +0.97). Additionally, those with prior exposure to tactile graphics training demonstrated larger gains in pre- to post-test performance (ES = +0.99). These findings highlight GTD as an effective tool for teaching diagram-based subjects to BVI students, providing equal access to mathematics and science. The study suggests that implementing GTD could help bridge the educational gap between sighted and visually impaired students in mathematics.

Keywords: *Geometry, Tactile Diagram (GTD); Blind and Visually Impaired Students, Visually Impaired Students, Sighted Students, STEM, Geometry Achievement (GAT).*

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I. INTRODUCTION

The global population of individuals with visual impairment is estimated to be approximately 1.1 billion, with 15% residing in Africa (WHO, 2019). In Nigeria, around one million people are classified as blind, and three million are visually impaired (Adelakun, 2020). Variability in classification criteria across studies has led to some inconsistencies in these estimates. Nevertheless, the number of blind and visually impaired is significant, underscoring the need for tailored support, particularly in education.

One of the challenges faced by blind and visually impaired (BVI) children in low- and middle-income countries is the lack of access to appropriate learning resources, which inhibits their ability to engage effectively with the school curricula. Mathematics, for example, is a compulsory subject in school because of the critical role it plays in technological development and its relevance in our daily lives, but it is also a subject that is often viewed as inaccessible to individuals with visual impairments. The lack of materials hinders visually impaired students' ability to learn key mathematical concepts, which are typically presented visually (e.g., graphs, equations, geometric shapes). Geometry, in particular, poses a substantial challenge for visually impaired students. Geometry deals with the measurement, properties, and relationships of points, lines, angles, surfaces, and solids. All this requires the learners to be able to see or visualise. Rosenblum et al. (2020) observed that visually impaired students often struggle with graphical elements in mathematics. They frequently express difficulty in achieving parity with their sighted peers on graphic-intensive problems (Zebehazy & Wilton, 2014).

Vision loss creates additional barriers in mathematics and science education, particularly with topics involving diagrams, graphs and charts (Adelakun 2020). This puts the visually impaired students at greater disadvantage than their sighted peers in mastering even basic mathematical concepts

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(Beal & Shaw, 2008). Given the visual nature of mathematics, it is crucial to ensure that visually impaired students have equal access to maths learning as their sighted peers.

Mathematics is integral to many high-paying, high-demand fields, particularly within STEM sectors (science, technology, engineering, and mathematics). When visually impaired students do not receive adequate math education, they are often excluded from these fields. This exclusion severely restricts their career options and employability, leading to higher rates of unemployment and underemployment within the visually impaired community. Consequently, the majority of visually impaired individuals often ended in low-wage, low-skill jobs, perpetuating economic inequality. Without equitable access to learning resources, visually impaired students are systematically excluded from opportunities that could lead to professional and social advancement.

Addressing inequality in access to basic maths is, therefore, urgent. This study is significant as it has potential to address the United Nation's' sustainable goal 4, that is, ensuring inclusive and equitable education for all.

Over the years, significant efforts have been undertaken by researchers and educators to make mathematical diagrams accessible to the visually impaired. A substantial amount of information is communicated graphically, which poses accessibility challenges for visually impaired individuals who rely primarily on tactile illustrations (Mukhiddiniv & Kim (2021). Tactile graphics are essential for students in science, technology, engineering, and mathematics (STEM) fields, as instructional materials in these disciplines frequently incorporate diagrams and geometric figures.

To facilitate access to printed materials, visually impaired individuals often rely on braille, a tactile writing system that enables perception through touch. Similarly, braille adaptations have allowed the visually impaired to access diagrams and images, providing an essential alternative to visual information. Studies suggest that the tactile modality, being analogous to vision in semantic and cognitive processing, may even surpass vision in assessing the material characteristics of shapes and objects (Luo et al., 2017). Through tactile diagrams, visually impaired individuals can perceive two-dimensional images. Tactile graphics, which are embossed outline drawings, are specifically created to help convey visual information to the visually impaired. Dahiya and Valle (2012) emphasized that tactile perception, encompassing sensations such as pressure, vibration, and temperature, plays a vital role in spatial awareness and environmental interaction.

Tactile diagrams make it possible for individuals who are blind or visually impaired (BVI) to have access to geometry. Edman (1992), who devoted over 30 years to creating tactile graphics, advocated for tactile graphics to be made more accessible. An example of tactile graphics is Geometry Tactile Diagrams (GTDs). GTDs are specifically designed to facilitate geometry instruction for BVI students. These diagrams, which include both print and braille labels, are tailored for use in inclusive classrooms by teachers who may not have specialized training in educating visually impaired students (Adelakun, 2020). This adaptation distinguishes GTDs from standard tactile diagrams, supporting sighted educators in delivering accessible instruction in special or inclusive school settings.

For such tactile diagrams to be used effectively in an inclusive classroom, Agrawal (2004) emphasised that they need to be adapted for use to meet the unique needs of the visually impaired. Various methods have been explored for producing tactile graphics relevant for the BVI community. Early efforts involved rendering graphic information in textual form, followed by manually designed images and thermoforming of tactile representations. More recently, automated methods have emerged. Thevin and Brock (2018), for instance, developed audio-tactile content from existing objects, while others have introduced tactile graphics production using special printers and embossers, such as the Index Braille Everest-D, PIAF, ViewPlus Tiger, and IRIE Embossers. Each of these devices offers distinct features and limitations in terms of functionality and adaptability.

While manually created or thermoformed tactile graphics require extensive preparation time, automated or computer-generated tactile graphics offer a more efficient alternative, albeit at a higher cost. Innovations such as audio-tactile graphics for blind students, created from real objects using augmented reality techniques, have introduced new possibilities in this field. However, challenges such as high costs and unreliable electricity supply limit the feasibility of these alternative forms in contexts like Nigeria.

An analysis of 257 studies published between 2015 and 2021 on the development and application of tactile diagrams provided valuable insights. The findings indicate that image processing techniques and audio information are widely used in the design of tactile graphics. Despite the geographical disparity in research focus, with certain countries contributing more significantly than others, the field is globally represented. Nonetheless, the production of tactile graphics remains a time-intensive and technically demanding process. The introduction of 3D printing technology has advanced this work, although it requires specialized expertise to create effective STEM-related tactile graphics. Diagrams created with swell paper have received positive evaluations from participants, who found them more natural and intuitive to interpret.

Mukhiddinov and Kim (2021) highlighted that refreshable tactile displays are prohibitively expensive for low- and middle-income populations and noted the absence of adequate training datasets for machine learning applications in this area. Therefore, alternative methods for creating tactile graphics are recommended. Research indicates that the tactile sensory system is superior to visual and auditory systems in accurately perceiving the characteristics of objects (Mukhiddinov & Kim, 2021).

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Previous research has provided some guidance on the design of tactile diagrams. Wu et al.'s (2022) research, for example, suggested that tactile diagram designs need to consider not just one factor, but also the scale, representation and complexity. They proposed textured-line drawing (TLD) for more effective representation, which is a combination of line drawings (LD) and textured pictures (TP). They also suggest that small-scale tactile graphics are more effective than medium-scale ones. For textured line drawings (TLD), both small and medium scales outperform large-scale graphics. Their study also suggests that TLD is generally more effective than LD (line drawing) alone. They advised that tactile graphics should be designed to enable exploration with both hands.

The aim of this study is to explore the potential of geometric tactile diagrams (GTDs) in facilitating the teaching of geometrical concepts in mathematics to blind and visually impaired students.

➢ *Purpose of the Study*

- To investigate the effectiveness of geometry tactile diagrams (GTDs) in facilitating geometry learning for blind and visually impaired (BVI) students.
- To determine the impact of prior tactile training on the utilization of GTDs by BVI students.

➢ *Research Questions*

- RQ1: How effective are GTDs in making geometry accessible to VI college students?
- RQ2: What impact does pre-exposure to tactile graphics training have on the performance of BVI students when using GTD?

➢ *Hypothesis*

- H_{01}: There is no difference in the geometry achievement test results of students taught using geometry tactile diagrams (experimental students) and those who were taught without geometry tactile diagrams (control students).
- H_{02}: There is no difference in the geometry achievement test results of BVI students who were previously trained to use tactile graphics and those who did not receive prior training.

II. THE INTERVENTION

The intervention used in this study was a set of tactile geometrical illustrations designed on the computer and were labelled in print and braille. They were printed with a special embosser. The development of these tactile diagrams went through different stages of production. The visually impaired member of the research team as well as two research assistants (a BVI and a mathematician) were present at every stage of the production to give feedback and revisions based on the suggestions were implemented. Taking advice from Sheppard and Aldrich (2001), we kept the design simple and not overloaded with information.

The tactile geometrical diagrams were used to teach concepts of area, perimeter, circumference and volume. The topics were: area of a triangle, perimeter of a rectangle and irregular objects, volume of a cylinder and circumference of a circle. They were used over four weeks of teaching simple geometry listed in the curriculum of General mathematics in the School of General Studies. Each topic was taught over a two-hour period within an inclusive classroom, in line with the curriculum. The control group participated in lessons on the standard college timetable, while the experimental group attended sessions in a separate setting. During these sessions, sighted students referred to diagrams in their manuals, and the BVI students explored the GTD diagrams relevant to each lesson. Both groups were given revision questions and classwork.

Both groups were instructed by the same instructor with extensive experience in working with BVI students and specific training on administering GTD and non-GTD instructional methods. To ensure consistency, standardized lesson plans detailing objectives, materials, and instructional techniques were utilized across all sessions. The instructor was unaware of the specific study hypotheses, focusing on delivering each session impartially. Moreover, an independent observer periodically monitored these sessions to verify instructional fidelity and adherence to the standardized lesson plans. The instructor presented GTD diagrams to the experimental group simultaneously with visual diagrams for the sighted students, thereby standardizing instructional timing.

Below are examples of the GTDs used in the teaching.

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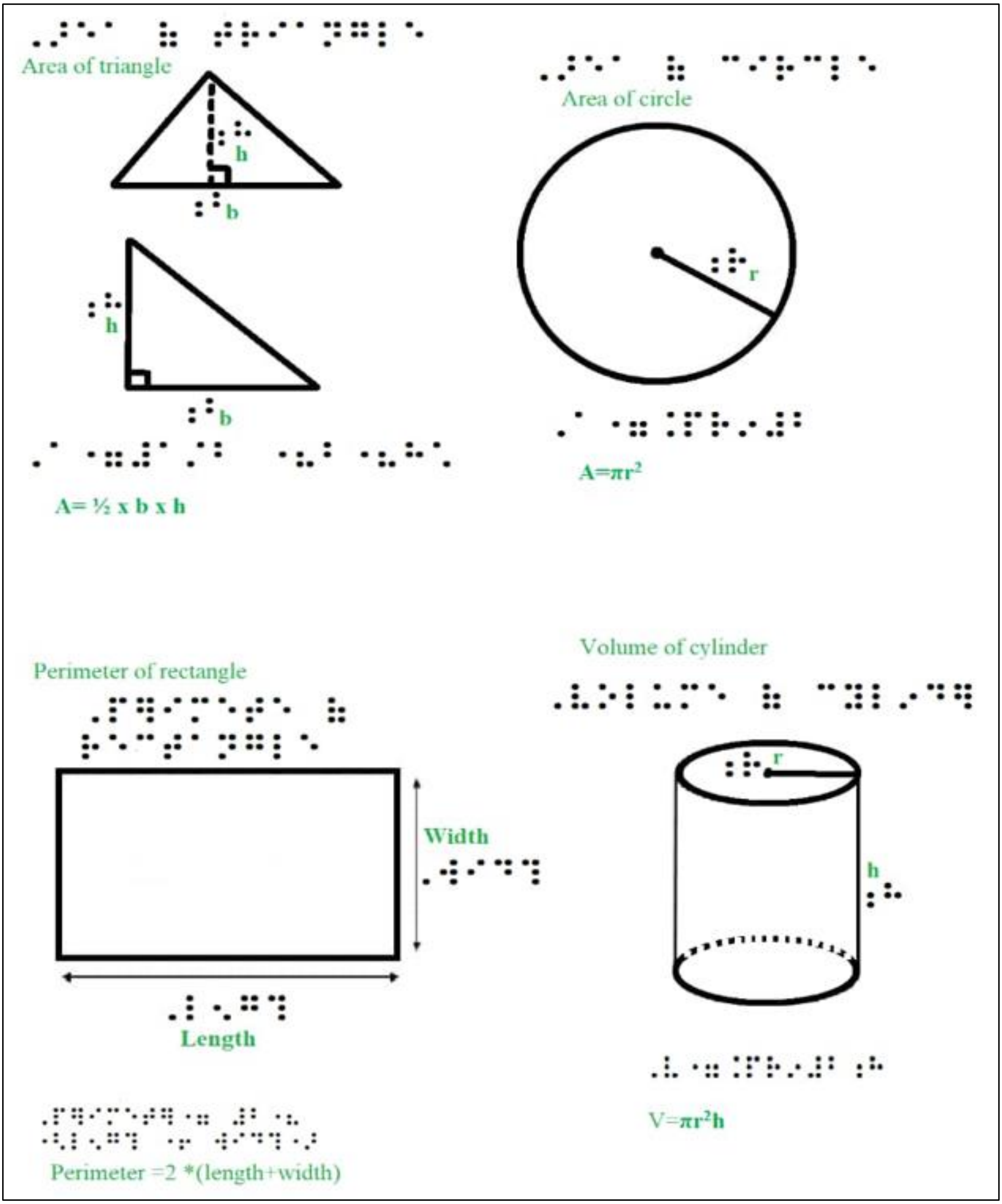

Fig 1 Sample Geometry Tactile Diagrams

The Geometry Tactile Diagrams (GTD) possess several unique design features that enhance their usability and accessibility for Blind and Visually Impaired (BVI) students. First, the diagrams incorporate embossed lines that allow BVI students to perceive shapes, dimensions, and structures through touch, which is fundamental to tactile learning and spatial understanding in mathematics. Second, they include both print and Braille labels, making it easier for BVI students and sighted teachers to communicate effectively about the lesson content, thus bridging any

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potential communication gap and enabling collaborative learning in inclusive classrooms. Third, these diagrams mirror the values and content provided to sighted students in classwork and assignments, ensuring that BVI students participate fully and consistently in assessments, without modifications that might create disparities in learning outcomes.

Additionally, these diagrams are designed to be natural and intuitive in their tactile layout, with deliberate spacing and simplified lines, which facilitate smoother exploration and comprehension for BVI students. This intuitive design reduces cognitive load, enabling students to focus on mathematical concepts rather than grappling with the diagrams' structure. Overall, these unique design elements underscore the GTD's role in fostering inclusivity, supporting both independent learning and teacher-student interactions, and ultimately making mathematics more accessible to BVI students.

III. RESEARCH METHODOLOGY

- *Trial Design*

The research design adopted for the study was a two-armed randomised control trial. Participants were 20 blind and visually impaired students from the Mathematics unit at the Authors Institution who must register and passed the general studies mathematics course. These were selected from 64 in the general studies course. Only those who were totally blind, who had congenital blindness or lost their sight before attending any school and agreed to participate were included. These students were in an inclusive classroom where they were taught with the sighted. All the BVI participants were braille readers who were already getting information through tactile means.

The participants were equally split by gender. Three-quarter of the participants were aged between 21 and 25. A quarter (25%) of them were aged over 30 (Table 1).

Once selected students were randomly assigned to either treatment condition where they were taught using GTDs (n =10) or to business-as-usual control where they received traditional instruction without the use of GTDs (n =10). Comparisons were also made between BVI students in the experimental group who had previously received training in the use of tactile graphics with those who had no prior training. Some experimental students received two hours prior to the experimental lecture on the first day to familiarize them with the tactile diagrams.

Table 1 Age of the Respondents

Age	Number	Percentage %
17-20years	05	25
21-25years	10	50
26-30years	02	10
30 and above	03	15
TOTAL	**20**	**100**

- *Ethics*

Ethical approval was obtained from the ethics committee of the Institution, informed consent forms completed by the invited participants were submitted to the committee and it was clearly explained to the participants that their participation was voluntary and that they could withdraw at any time.

- *Impact Evaluation*

The primary outcome was students' performance on the Geometric Achievement Test (GAT). Effectiveness of GTD on GAT was measured using the difference in the mean test scores of the two groups divided by the pooled standard deviation, expressed as Hedges' g. Hedges' g is more appropriate for use when sample size is small or when the groups are not even, which is the case here.

The secondary outcome was the impact of prior training on students' performance on the Geometric Achievement Test (GAT), comparing treatment students who had received prior training in tactile graphics with those who had no prior training. Impact was also measured using Hedges' g effect size.

Performance in geometry was assessed using a researcher-developed test. The Geometry Achievement Test (GAT) comprises 20 items. Senior lecturers in the department of mathematics in the same college and visually impaired lecturers in the visual impairment education department and students in other departments who are sighted and those with visual impairment were consulted in the development of the test to ascertain the appropriateness for its intended use. Revisions were made following their feedback on the content and construct validity.

The same test was administered to the experimental and the control groups. The BVI took the test on a computer and the answers were printed for the researchers to assess while sighted participants took the pen and paper test. The tests were scored over 20 marks.

IV. RESULTS

- *How Effective are GTDs in Making Geometry Accessible to VI College Students?*

The results show that students who received instruction using geometry tactile diagrams, significantly outperformed the control group (Table 2). The effect size of 0.97 suggests that GTD has a beneficial effect on BVI students' learning in geometry. The large effect size is likely due to the very small sample size (Slavin & Smith 2009).

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Table 2 Impact of GTD on Students' Geometric Achievement

	Pre-mean scores (standard deviation)	**Post-mean scores (standard deviation)**	**Gain scores**	**Effect size**
Experimental group (n =10)	8.4 (1.183)	9.69 (1.80)	1.29 (1.55)	
Control group (n = 10)	7.1 (1.47)	7.1 (1.41)	0 (1.41)	0.97
Overall	7.75 (1.80)	8.39 (1.41)	0.64 (1.334)	

- *What Impact does Pre-Exposure to Tactile Graphics Training have on the Performance of BVI Students when using GTD?*

To see whether pre-exposure to training in using tactile diagrams accords any additional benefits, we compared the achievement scores of those in the experimental group who had prior training with those who did not. The results show that the group with pre-exposure to training in tactile graphics have a greater advantage than the group without (ES = 0.997).

Table 3 Comparing Achievement Scores of the Experimental Group with and without Pre-Exposure Training

Group	**Means**	**S.D**	**S.D*$_{looped}$**	**Hedge's g**
Pre-exposure to training (n = 5)	9.3	1.1832	1.3038	0.997 ~ 1.0
Non-exposure to training (n = 5)	8.0	1.4142		

This finding suggests that pre-exposure training has a substantial positive impact on the use of GTD and by extension their performance, potentially enhancing the usability of the tactile graphics. However, it is important to note that this study was conducted under specific conditions and with a relatively small sample size. Further research is needed to confirm these findings and explore the generalizability of the results to diverse populations and contexts.

The results look promising suggesting the benefit of using geometry tactile diagrams in teaching geometry. These findings will be relevant to teachers and teacher educators of BVI students, offering them access to a potentially beneficial teaching and learning tool for teaching Geometry.

The findings could have significant implications for policy. Based on these positive outcomes, educational institutions at the federal, state, and local levels, along with non-governmental organizations, might consider supplying GTDs to schools to support mathematics education for students with visual impairments. Additionally, GTDs could be introduced in mainstream schools to give visually impaired (BVI) students access not only to mathematics but also other visually intensive subjects, such as science.

V. DISCUSSION OF FINDINGS

The study investigates the impact of the use of Geometry Tactile Diagrams in making geometry accessible for BVI students and explores the effect of pre-exposure to tactile lines, curves, and graphics on students' understanding. The GTD, produced with swell paper, has shown promising results. The benefit of tactile graphics has been demonstrated in other studies reviewed by Mukhiddinov and Kim (2021). Our findings are consistent with Sheppard and Aldrich (2001), who reported positive feedback from teachers on tactile graphics, and similarly shows that tactile graphics improves BVI students' access to visual information presented to sighted peers.

A unique contribution of this study is the impact of structured pre-exposure training, which provides BVI students familiarity with basic tactile elements before using GTD. Mukhiddinov and Kim (2021) did not extensively explore the role of preparatory tactile training, so this study adds valuable insight by demonstrating that prior exposure significantly enhances student performance. Such training may be an essential component for effective tactile graphic implementation.

This study also reinforces the value of tactile graphics in STEM education, as identified by Mukhiddinov and Kim (2021), who noted that diagrams and charts represent over 70% of STEM instructional materials. GTD thus addresses a critical educational need, providing an accessible alternative that supports BVI student success. Mukhiddinov and Kim's review also found that many tactile graphics lack a user-centred design. By involving BVI students in the GTD production process, this study ensures GTD's intuitive usability and aligns directly with their recommendations for improvements in tactile graphic design.

Furthermore, this study highlights teacher training as a critical factor in the effective use of tactile graphics, a focus absents in Mukhiddinov and Kim's study (2021). Training teachers on GTD use improved classroom integration, suggesting that future research should explore how educator preparedness impacts tactile graphic effectiveness in STEM education. Finally, GTD provides a practical, cost-effective solution in resource-limited settings, addressing accessibility challenges. Unlike some less accessible formats, GTD's swell paper design allows for easy exploration by touch, making it a scalable tool to enhance tactile learning for BVI students and filling a critical gap noted in the literature.

VI. IMPLICATIONS FOR FUTURE EDUCATIONAL RESEARCH AND DEVELOPMENT

The success of GTD in enhancing geometry accessibility for BVI students suggests several promising directions for future educational research and development. First, further studies could explore how GTD impacts BVI

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students' comprehension across other STEM disciplines, such as physics and engineering, where complex diagrams and spatial representations are crucial. Research could examine how GTD, possibly adapted for diverse subjects, helps BVI students navigate technical concepts that are otherwise difficult to access through text alone. Expanding GTD applications in these areas would offer insights into how tactile graphics could bridge learning gaps across the broader STEM curriculum.

Moreover, future research should focus on optimizing pre-exposure training methods that introduce tactile elements like lines, curves, and spatial relationships before using GTD. Such preparatory training has shown initial success in this study, but further investigation could refine best practices and establish standardized training protocols that maximize tactile learning outcomes. Research could explore variations in tactile training duration, content complexity, and instructional delivery (e.g., individual versus group learning) to understand how best to scaffold tactile literacy for BVI students before introducing subject-specific tactile graphics.

Developing a repository of GTD-based educational resources is another area with far-reaching potential. A standardized, easily accessible library of GTD materials for different subjects and grade levels could make tactile resources readily available to educators worldwide, particularly in low-resource settings. Such repositories could benefit from ongoing research into the most effective GTD designs and content-specific adaptations for visually impaired learners, building a globally applicable toolkit for inclusive education.

In addition to expanding GTD's subject applications, future research could investigate how technological advancements could complement GTD for BVI students. Integrating GTD with audio descriptions, digital touch-sensitive feedback, or even augmented reality tools could provide a richer, multimodal learning experience. For example, combining tactile and auditory cues could deepen students' understanding of complex diagrams, enhancing both their spatial reasoning and content retention. Understanding how these multimodal methods impact BVI students' cognitive processing and academic performance could set the stage for future GTD innovations that go beyond traditional tactile methods.

Lastly, this study highlights the critical importance of teacher training in using tactile graphics effectively. Future development efforts should investigate how best to equip educators with the skills and confidence needed to teach using GTD and other tactile tools. Research into teacher training models for tactile graphics could clarify the methods and support systems that most effectively prepare educators to teach BVI students in STEM fields. This might include professional development modules, peer-learning groups, or digital resources that guide educators in tactile graphic use, particularly in inclusive classrooms.

By addressing these avenues, future research and development efforts could significantly enhance the utility of GTD for BVI students, creating a more inclusive and accessible educational landscape that bridges the gap in STEM education.

VII. LIMITATIONS OF THE STUDY

While this study provides valuable insights into the effectiveness of GTD in enhancing geometry accessibility for BVI students, several limitations should be noted. Firstly, this study did not include a comparative analysis of different tactile graphic types, such as line drawing (LD), textured picture (TP), and textured-line drawing (TLD), which could offer a broader understanding of how various tactile representations influence BVI students' comprehension and spatial reasoning. Instead, a single type of tactile graphic, GTD, was employed, though it was designed to support exploration with both hands, as recommended by Wu et al. (2022). Future research may benefit from evaluating a range of tactile graphic formats to determine their relative effectiveness in supporting BVI learners.

Additionally, this study was limited to assessing BVI students exclusively, with sighted student performance evaluated separately and published in another paper. While this approach allowed a focused analysis of GTD's impact on BVI learners, integrating both sighted and visually impaired students within the same study could offer insights into comparative outcomes and instructional strategies within inclusive educational settings. This focus solely on BVI participants means that findings may not be fully generalizable to mixed-ability classrooms without further research.

Finally, the sample size was relatively small, which may limit the generalizability of findings. Future studies with larger and more diverse samples could help validate these results across different educational settings and ensure broader applicability. Additionally, the study did not explore the long-term retention of geometric concepts acquired through GTD use, leaving room for future research to assess whether the initial gains observed are sustained over time.

These limitations suggest that additional studies are needed to further refine GTD approaches, evaluate different tactile graphic types, and expand understanding of GTD's role within both specialized and inclusive STEM education for BVI students.

VIII. CONCLUSION

Mathematics, with its visually-intensive content, has often been perceived as a challenging subject for students with visual impairments. Many educators view it as an area beyond the capacity of the visually impaired. However, advancements in tactile and assistive technologies are expanding access to mathematics education. This study highlights the importance of using appropriate tactile diagrams, such as Geometry Tactile Diagrams (GTD), and

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relevant instructional strategies to make geometry accessible to Blind and Visually Impaired (BVI) students. By adopting GTD, teachers can bridge the mathematical gap between sighted and visually impaired students, fostering a more inclusive learning environment. Finally, this study underscores the importance of using the right tools and teaching methods to facilitate accessibility to subjects, such as mathematics for BVI students.

RECOMMENDATIONS

The findings of this study highlight several key recommendations to enhance educational accessibility and outcomes for Blind and Visually Impaired (BVI) students, particularly in mathematics.

Government bodies at federal, state, and local levels, alongside Non-Governmental Organizations (NGOs) and private sector partners could consider supporting the provision of GTD (Geometry Tactile Diagrams) and other tactile educational resources in institutions that serve BVI students. Increased access to these materials could contribute to a more inclusive and effective learning environment. In addition, teachers working with BVI students require specialized training to use GTD and other tactile resources effectively. The use of GTD could be part of the training for pre-service teachers. Equipping teachers with the skills to integrate tactile materials into their teaching practices is essential, as is providing them with ongoing professional development and support to ensure they remain informed about best practices.

Furthermore, teachers should monitor students' use of tactile diagrams to ensure that these valuable resources are used properly and preserved for future classes. Schools and educational institutions are encouraged to implement systematic maintenance routines and allocate funds specifically for the upkeep of tactile materials, as these resources are intended for repeated use and should benefit successive cohorts of students.

While this study focuses on geometry, there is a compelling need to expand tactile resources to other mathematical areas requiring spatial understanding, including algebra, trigonometry, and calculus. Developing and testing comprehensive tactile toolkits for these subjects in classroom settings will further open mathematics to BVI students. Additionally, tactile diagrams and GTD should be integrated as essential components in mathematics laboratory kits in BVI-serving educational institutions, where they can facilitate a more inclusive learning experience and support BVI students in excelling across mathematical subjects.

Looking forward, collaborative research and development initiatives involving educators, designers, and BVI students are recommended to advance cost-effective and durable tactile graphics that can withstand frequent classroom use. Creating these resources with user-centred design principles can yield diagrams that are both effective and intuitive for BVI students.

Finally, it is crucial that advancements in GTD and tactile resources are shared broadly with educators, policymakers, and stakeholders. Through awareness campaigns and educational conferences, stakeholders can build a unified understanding of the importance of tactile learning aids and secure greater support and funding for accessible educational resources. Together, these recommendations aim to build a more supportive and inclusive educational landscape for BVI students, particularly in STEM subjects like mathematics.

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