TECHNIUM
SOCIAL SCIENCES JOURNAL

www.techniumscience.com

Vol. 68/2025

A New Decade for Social Changes

PLUS COMMUNICATION

International Communication & PR

Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
ISSN: 2668-7798
www.techniumscience.com

Enhancing Access to STEM Graphics for Blind and Visually Impaired Students in Nigeria

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Abstract. Mathematics, Science, Engineering and Technology (STEM) are fundamentals in education with numerous advantages for students. They foster creativity, cultivate critical thinking and, more importantly, open career opportunities. However, for those with visual impairment, these avenues are limited. Blind and Visually Impaired (BVI) students face significant challenges in accessing mathematics and science curricula due to the visual nature of the content. Addressing these challenges would involve rethinking methods of delivering lessons and alternative educational resources. In a cross-sequential study employing observation, unstructured interviews, and critical analysis of documents, this paper assesses the impact of the tactile diagrams component of a STEM Kit on students' performance in mathematics and basic science and technology (BST). The findings reveal increased participation of BVI students in classroom activities, with notable improvements in their performance in mathematics and basic science and technology. Positive effects were also observed in enhanced participation recorded in other subjects during the study period. These findings underscore the importance of inclusive educational tools in promoting active engagement, academic success, and overall educational equality for blind and visually impaired students in terms of access to STEM, particularly in low- and middle-income countries where such resources are not often readily available.

Keywords. STEM, Basic science and technology, Mathematics, Tactile graphics, visual impairment, Blind

1. Introduction

In almost all societies, knowledge of maths, science and technology opens up opportunities not only for individual students, but also for society. This is increasingly pertinent in our highly technological and computerised world. STEM subjects cultivate critical thinking and problem-solving skills. Proficiency in these subjects opens up a wide array of career paths. Students who do well in these subjects are in high demand and have good career prospects. However, for those with visual impairment there are particular challenges in accessing these subjects. One main reason is that these subjects tend to be very visual, requiring observations and drawings. While children in the developed world may have access to sophisticated ways of teaching and learning, for example, assistive technologies in laboratories, audible

Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
ISSN: 2668-7798
www.techniumscience.com

thermometers, refreshable Braille displays, talking devises, and tactile interfaces and tactile diagrams and models, those in low- and middle-income countries often have no access to these due to the high cost of such tools.

The World Health Organisation estimated the population of persons with mild to severe visual impairment to be 2.2 billion. There are no records of the existence of BVI in STEM fields all over the world, literature search only reveal a huge shortage of BVI receiving adequate education in different parts of the world and mention is made of the very low representation in the STEM fields despite the fact that many research established that the BVI have equal cognitive ability like their sighted peers. They are able to perform equally or better than their peers. Therefore, their low representation is not due to their inability but the level of accommodation and acceptance provided in the environment determines their access to STEM (Blatt, 2022)

A review of research on representation of the BVI in STEM careers shows huge underrepresentation in many countries Tekane and Potgieter (2021). Even, 2017 Survey only estimated that 39% of the working age American blind are employed and generally the unemployment rate of the blind is 2.5 times higher than their sighted peers. the percentage in STEM fields was not stated. Specifically, they are underrepresented in STEM fields, according to Bell & Silverman, (2019) in a survey conducted among youth 10 to 18 years on their interest in STEM. Only 15.9% of the estimated number of persons with vision impairment earn a Bachelor's degree or higher in the United States from the 2017 survey. Some BVI studied and excel in STEM and are employed in the appropriate fields, Adelakun (2013) highlighted some of them and Greenval et al 2021 also presented a blind professor teaching a bioengineering course which is another example of blind person in the STEM field.

Over the years researchers propose strategies and adaptations that could enable access to STEM, though not supported with research evaluations. Among the few evaluated researches, Harjoe et al, (2023) redesigned the biology laboratory and suggested general modifications that could enhance access to BVI. Well-resourced and effective disability unit was suggested in a research conducted in South Africa Tekane and Potgieter 2021. There is a report of provision of 3D models and tactile maps of objects in the UK special schools however emphasis is laid on attitudes of teachers in mainstream schools since there is a shift towards mainstreaming Hayes and Proulx (2023). It was established by Silverman and Bell (2020) that BVI who receive early mentoring and support in school develop interest in STEM and perform appreciably. Singh et al (2023) evaluated Educational Software System For Teaching STEM To Visually Impaired People to address the problem of non-existence of adequate teaching learning materials to ease access to science and mathematics to BVI school children and might make them choose STEM careers after middle school. Access to tactile graphics receives attention from many organisations and individuals because it's the only way to teach or present non-textual information (diagrams, graphs, and maps) that dominate STEM to the BVI. The visual nature of science and mathematics makes alternative representation of diagrams and images very important and indispensable for equal and adequate access to STEM by BVI irrespective of the development in technology. Many research institutes and institutions had made and are still making efforts on access of tactile graphics to the BVI.

Tactile graphics are made in different formats with different materials. They can be hand made with spurwheel and different textured paper and using different textured materials to represent surfaces as well as using different strength of thread to demarcate parts of objects. This is very difficult and time consuming for teachers or support staff, moreover it requires skills that are often not possessed by them. Improved tactile graphics are made with embossers like Everest embosser, ViewPlus (also called Tiger) embosser or printed on swell form paper then embossed with Swell form machine. There are recent electronic presentations of graphics. The graphics produced by each method have specific features which may make one preferred to the other. Some of the graphics are available online (Tactile graphic library) for use by those who have the type of embosser needed to produce the tactile graphics.

The tactile diagram used in this research is unique for having the print and braille labels on the graphics which remove the communication problem between the BVI and the STEM teachers who are mostly non-specialists in the education of persons with visual impairment.

The Nigeria national policy on special needs education addresses the challenges, needs and prospects of improving the current status and contents of the section on special needs education in the previous National Policy on Education. The policy identifies that the current practices are far from expected best practices. Like in other countries, There is no adequate data of the current BVI in STEM fields. The policy is to achieve access and equity as prescribed by UNESCO. A particular emphasis is laid on resources to enhance equal access to all round education like their peers without special needs.

To reduce inequalities in education and promote inclusivity, addressing two of the United Nations Sustainable Development Goals, efforts have to be made to ensure that all children have equal access to STEM subjects. In some countries, such as Nigeria, children with visual impairment are routinely excluded from STEM because resources are not available to cater to their needs or because teachers are not trained to implement these resources. Visual impairment should not be an excuse to exempt individuals from receiving adequate education (Reynaga-Peña, et al (2020); Cryer, 2013) as emphasised by the Nigerian National Policy on Education.

One of the main challenges for BVI students is that in STEM subjects much of the information is presented in graphics and diagrams. BVI students can read such graphs and diagrams using raised-line drawings and tactile models to represent graphs, diagrams, and scientific structures, allowing tactile exploration and comprehension. These can be read with the tips of their fingers. Such tactile graphics are essential to STEM study for BVI because around 70% of information in science textbooks are visually presented (Ferro and Pawlum 2013). In the absence of any tactile graphics, BVI have to rely on their sighted peers to interpret or translate the pictures or diagrams. This can cause confusion and also errors in interpretation especially in describing complex graphics. Consequently, teachers and BVI mistakenly conclude that STEM is not for the visually impaired.

Even if tactile graphics and other tools are available, BVI may still not be able to access STEM subjects. In many low- and middle-income countries, teachers are often not trained to use such tools. In Nigeria, for example, teachers teaching STEM are often sighted and may not know the needs of BVI students, while specialist teachers with training in teaching BVI are not trained to teach STEM (Adelakun, 2017). Without adequate training in the use of tactile graphics, teachers are unable to use them (Ladner et al. 2005). The aim of this study is to appraise a bespoke tactile diagram that has both braille and print labels that can be read by the BVI, sighted and specialist teachers. This is to remove communication challenges between the sighted teachers and the BVI students. This tactile diagram had been tested and evaluated with secondary school students as part of the PhD study of the lead author (Adelakun, 2017). The findings of this study (Adelakun, 2020) suggest that such learning tools should be introduced early to primary school students. The study found that by the time BVI students reach secondary school, most would have dropped out of STEM. It is hoped that this intervention will open accessibility to STEM subjects for BVI students to encourage the takeup of STEM subjects at

Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
ISSN: 2668-7798
www.techniumscience.com

secondary level. The aim of this new study is to evaluate the usefulness of the tactile diagrams for primary school children.

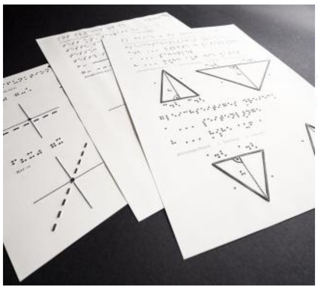
Learning and understanding graphical illustrations is particularly necessary for individuals who study or work in areas such as engineering, technology, economics, mathematics, and science. Pictures, diagrams or graphics form an essential part of STEM and most of the time are not accessible to the BVI. There has been much research on tactile graphics for BVI. Rosenblum and Herzberg (2015) evaluated four tactile graphics made using different production methods and found that clarity of information is important if graphics are to be useful. The authors further suggested involving the users in co-creating the product so their suggestions can be incorporated in the design. They also recommend having the tactile graphics all the time during the teaching and not only after the classroom teaching. These are useful suggestions, which we have taken into account in this study.

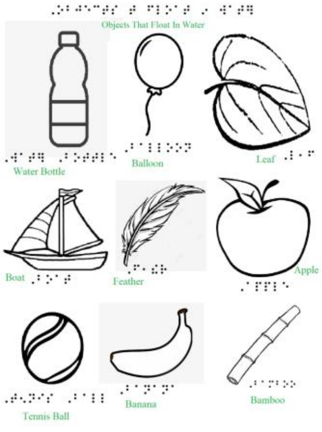
1.1 The intervention

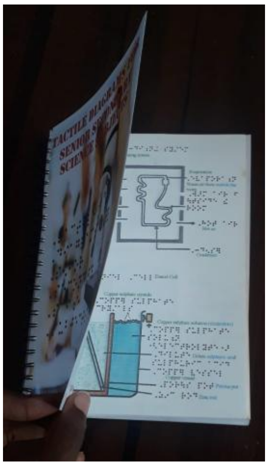
One of the barriers to access to STEM learning for BVI students in Nigeria was that teachers teaching STEM were often sighted and not trained to teach BVI (Adelakun, 2017). They were not aware of the challenges and needs of BVI students. On the other hand, specialist teachers trained to teach BVI were not subject specialists, and so were unable to interpret tactile graphs and diagrams. This communication breakdown between the BVI and the teachers of mathematics and science is a major barrier to access STEM subjects. The BVI cannot see the diagram drawn on the board or the ones inside their textbooks. Specialist teachers, on the other hand, cannot explain the diagram to the BVI as they have little knowledge of STEM themselves.

To overcome this simple yet unaddressed issue, we designed bespoke tactile graphics for the STEM Kit®. The STEM Kit is a copyright name of the product marketed by the Science and Technology for Nigeria Persons with Special Needs Initiative. It is designed for teaching mathematics and drawings to persons with visual impairment. There are two components in the Kit: a metallic board and magnetic tiles in a box for teaching calculations to BVI by sighted teachers and tactile graphics designed for primary and secondary school children. These graphics are printed on a swell form paper and then embossed with the embosser. They were first designed and labelled in print and braille on the computer and then later printed and embossed. The production of the graphics followed the recommended standard of tactile graphics in terms of scale, representation and complexity (Wu et al., 2022). According to Wu et al., small-scale graphic was recognised faster, textured line was easy with medium sized graphics and are helpful for identification. They recommended that large-scale graphics should be reduced to the size that allows BVI to hold them easily in two hands.

This research is concerned with tactile graphics for primary school students. In primary science these tactile graphics are bound together as a book. Separate ones are produced for mathematics. Each graphic is made of raised lines of different or single weight labels in both print and braille labels.







2. Research Methodology

2.1 Research Questions

The study aims to answer the following research questions:

RQ1: How do teachers perceive the usefulness of tactile graphics on the participation, performance and peer interactions for primary BVI students in maths?

RQ2: How do teachers perceive the usefulness of tactile graphics on the participation, performance and peer interactions for primary BVI students in science and technology?

RQ3: From the teacher's perspective is there any difference in the level of participation, performance and peer interaction between BVI students and others?

This study employed a cross-sequential research design to find out the usefulness of tactile graphics on the participation, academic performance, and peer interaction of primary students with visual impairments in mathematics and basic science and technology within mainstream educational settings. In a cross-sequential design, data is collected at specific points in time in two or more groups. It is a combination of longitudinal and cross-sectional features. A follow-up is conducted on the group two or more times, which gives the cross-sectional its longitudinal aspect' (Kujala et al 2019). Cross-sequential research design was adopted whereby fewer participants were studied over time in this study four pupils were observed over six academic school terms. The small number of participants makes it easy to control different variables. However, the method has disadvantages of the possibility of participants providing biased responses and attrition. However, longer observation will reduce the effect of the identified disadvantages. It corrects the low internal validity which is known as the disadvantage of cross-sectional and longitudinal effects because of the difficulty to rule out intervening variables.

Cross-sequential features allow researchers to study different age groups within a short time. It is also called accelerated longitudinal" or "convergence" design or ''short-term longitudinal design''. A more detailed analysis of the different changes or observations will reduce the effect of the intervening variables. It's a sort of meta-analysis where multiple research studies answer the same research question. Observations on BV1B2 can be taken as Study 1, BVIB3a and BVIB3b can be taken as Study 2 and BVIB4 can be considered as Study 3. All the research studies answer the same research question.

Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
ISSN: 2668-7798
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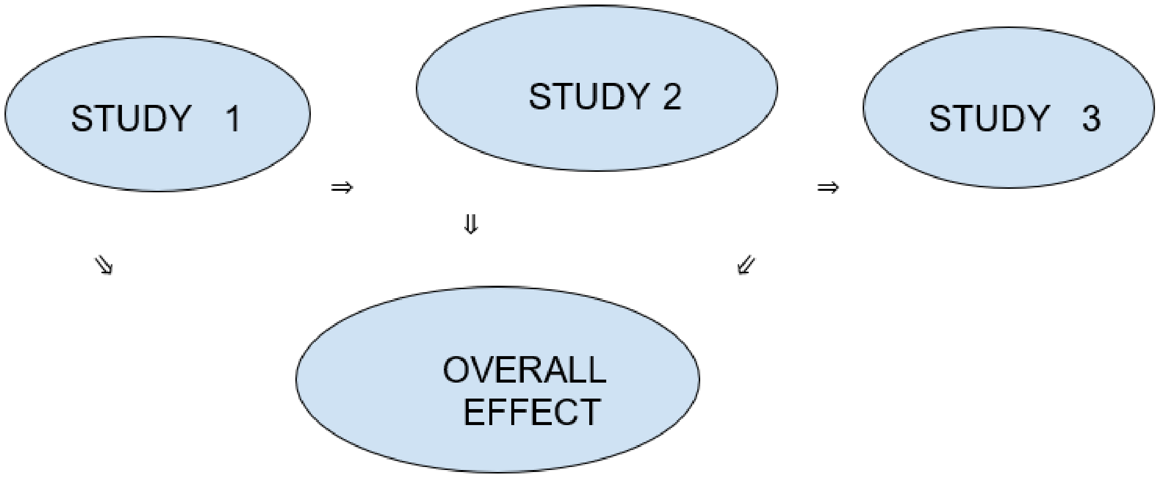
Figure 1. The model of cross-sequential study adopted.



This study generates datasets comprising class and observation time information, allowing us to investigate observation time on the study. In this study, we want to investigate the factors that account for the observed rise in involvement within the context of a Multilevel model. The fundamental pattern refers to the overall trajectory of the observations, which is subsequently evaluated and deliberated upon.

2.2 The Trial

The study encompasses two consecutive academic sessions within a conventional educational institution. The educational institution has a longstanding tradition of integrating students with diverse special needs, including individuals with vision impairments. The population included all students with visual impairment in the school, only 4 were included in the research based on specific criteria (have total blindness and ethically their parents agreed to their participation). Three of the remaining students have partial sightedness and the parents of the remaining students did not allow them to participate. The four involved in the research belong to Basic 2, Basic 3 and Basic 4. They were observed over two academic years at six time points at the end of each school term.

The study featured four primary school pupils, who were presented with STEM Kit Tactile diagrams for the mathematics and basic science and technology (BST) topics during two academic sessions in their respective classes. This means they were observed and evaluated for academic six terms while the teachers used tactile diagrams for them during mathematics and basic science and technology lessons. Their previous performance was examined before the start of the research and at the end of each term with the same examination questions done by their sighted peers.

Remote video recording of data was sometimes used and the video was sent through email or WhatsApp weekly immediately after the class. This was cross analysed with physical observations by the teachers and the researcher. This was also used to control the measurement effect which is attributed to the presence of an observer in the classroom, ethical concern of the secret observation was included in the informed consent given to the participants. For instance, the parent of one of the two BVI in basic 5 was not pleased with the recording and basic 5 was removed from the study. Video recording is less intrusive to researchers' presence in the classroom and this also allows greater flexibility too as we do follow up interviews.

In addition to the termly examination a twenty items observational checklist was prepared and was validated by stakeholders [lecturers, BVI among lecturers, post basic BVI, Basic science teachers in another school, BVI in basic school in another school in another city] Their suggestions were considered and used to modify the checklist. The final checklist was submitted with the research ethics application in the college where the authors work] Approval was given for the conduct of the research. Informed consent was distributed to teachers and the one for the Pupils was sent to their parents through the teachers after giving adequate explanations to the BVI involved in the study as well as the sighted classmates.

Before the evaluation commenced, the teachers and the pupils were trained separately for two hours and one hour together. The details of the teachers training include strategies to be used to include the BVI in the teaching in the mainstream class. The pupils were taught how to interpret diagrams; the training was done with a duration of 30 minutes each to avoid boredom. The last 30 minutes was done in the classroom to create awareness with the sighted pupils in the class. They were made to understand the reasons for the study and familiar with sample diagrams to be used by the BVI during subsequent lessons.

The trained research assistants use the observation checklist for 60 real time observations. Two people completed the checklist individually and later compared, inter-observer reliability checks for quality and quantity of instructional interactions, average observation of the BVI on the tactile diagrams was 15 minutes. Classes were also video recorded to allow inter-observation, this also reduces interruption and missing of significant moments during the observations.

The tactile graphics in the STEM Kit were examined for conformity with these standards. The information is clear and they conform with the tested standard. They were tested with other basic pupils and secondary students who have visual impairment. The comments were good. The diagrams were tested in other studies and are judged to be good and are recommended for use in schools for teaching BVI (Adelakun, 2020)

Skills to read tactile graphics and provision of the tactile graphics

The four BVI were braille readers, this means they already use tactile means to read. They were trained to identify different raised/embossed lines and curves, followed by shapes. They were involved in simple identification games. Sample tactile graphics which are different from the ones to be used in the research were used during the training with research assistants, teachers and the BVI.

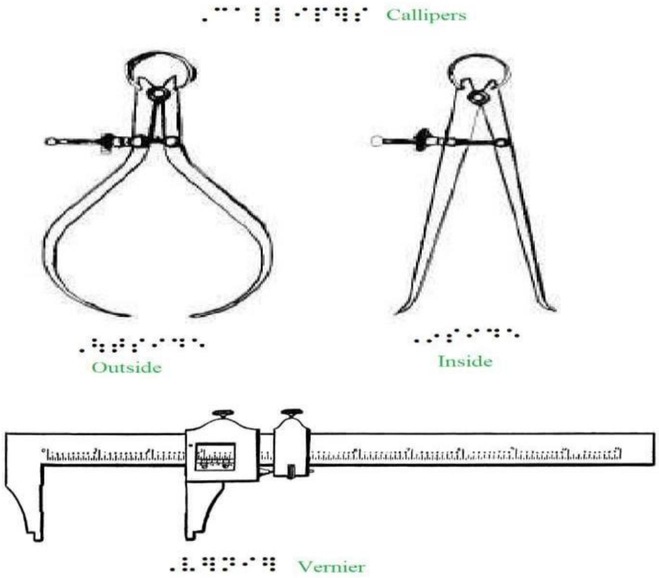
The Tactile graphics in the mathematics and BST curriculum and textbooks are already produced and packed with the STEM Kit. These diagrams were purchased from an NGO supporting access of science and technology for special needs students [SCIENCE AND TECHNOLOGY FOR NIGERIA PERSONS WITH SPECIAL NEEDS INITIATIVE] These were supplied to the Headmaster of the school. A meeting was held with the resource room managers [who are special needs coordinators[SENCO] and the headmasters, this is to ensure that the relevant diagrams were supplied to the teachers when needed. And the checklist and video are connected and switched on and off when necessary.

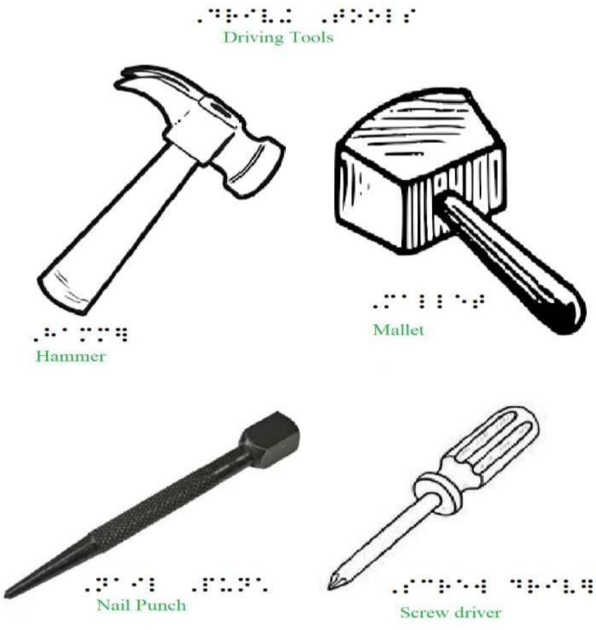
The teachers are expected to use the tactile diagrams whenever they teach, however the teachers are to complete the checklist once in a term making 3 recordings in a session for a pupil since there are 3 terms in a school session. The video is put on only during the mathematics and basic science and technology class by the SENCO. There were initial interviews with the

Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
ISSN: 2668-7798
www.techniumscience.com

pupils and teachers, followed by checkings of their previous class and examination records. Separate checklists were completed for each subject [mathematics and basic science and technology]. Five items of the checklist were focused on before the study commenced, the next five questions were on the observation of the teacher focusing on participation, the next five focused on the performance and the last five focused on interaction between peers. The teachers used the tactile graphics in the book during examinations for BVI in place of printed diagrams in the printed questions.

Sample pages of the Tactile Graphics books used.





Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
ISSN: 2668-7798
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3. Results

Initial interviews of the three teachers were conducted around if the BVI takes part in mathematics lessons and also basic science and technology. They were also asked to explain reasons for their responses.

From the school records, the BVI in the school has not been participating in mathematics examinations as no scores are recorded on mathematics in their previous results. They have scores in BST but none of the BVI scored 40% in the past two years examined. From the follow up interviews the teachers and pupils' responses confirm the record. The tactile graphics were used in the examinations for the six terms. The results is presented

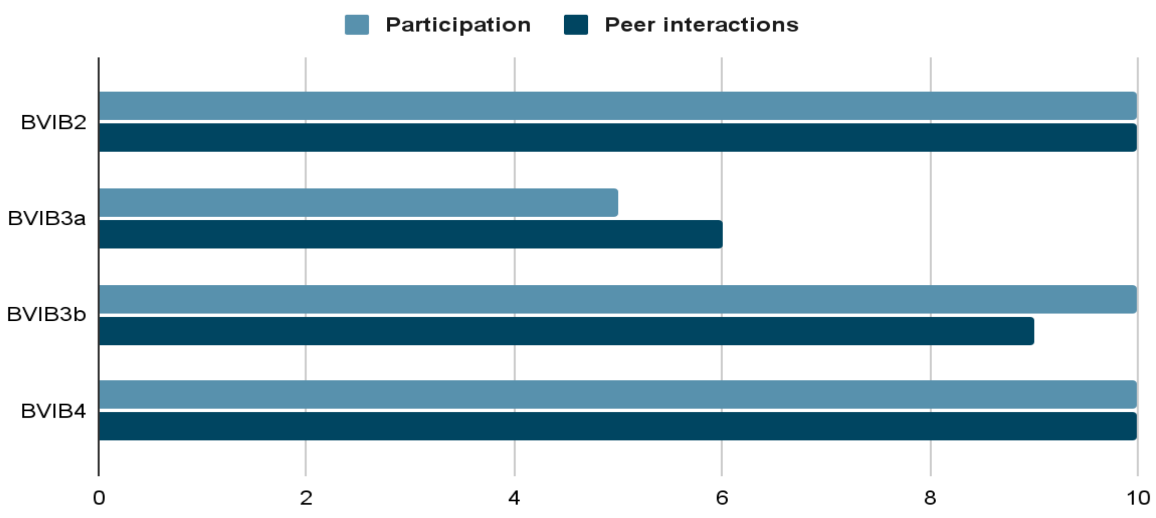
The BVI and sighted peers' interactions in the class was not encouraging, they tend to sit alone and only talk to peers occasionally. Don't likely initiate discussions with peers though they respond to questions when asked.

They were asked to rate the participation from 0 to 10 [10 being the highest]. They were asked what the pupils used to do during the lessons. What effort has the teacher done to make the subjects accessible to the BVI. [Rate their interactions with the sighted in the class from 0 to 10 [10 being the highest] Their performance in other subjects is also rated from 0 to 10.

The rating is presented below for the 4 pupils. BVIB2 is an acronym for Blind and visually impaired Basic 2, BVIB3a and BVIB3b are for Blind and visually impaired in Basic 3, for the two BVI in basic 3. BVIB4 is used for the BVI in basic 4.

At the end of the study, below is the overall effects on participation and peer interaction with the classmates.

Figure 2: Participation in lesson and Peer interactions with the peers



Comparing with their sighted peers, at the end of the study, the participations and interactions that are difficult for the teachers to score at the start of the study have been scored good ratings, for BVIB2 and BVIB4 the peer interactions is rated 10. Participation of one of the basic 3 BVI is also scored 10 while the peer interaction was scored 9. The participation and

Technium Social Sciences Journal
Vol. 68, 235-250, February, 2025
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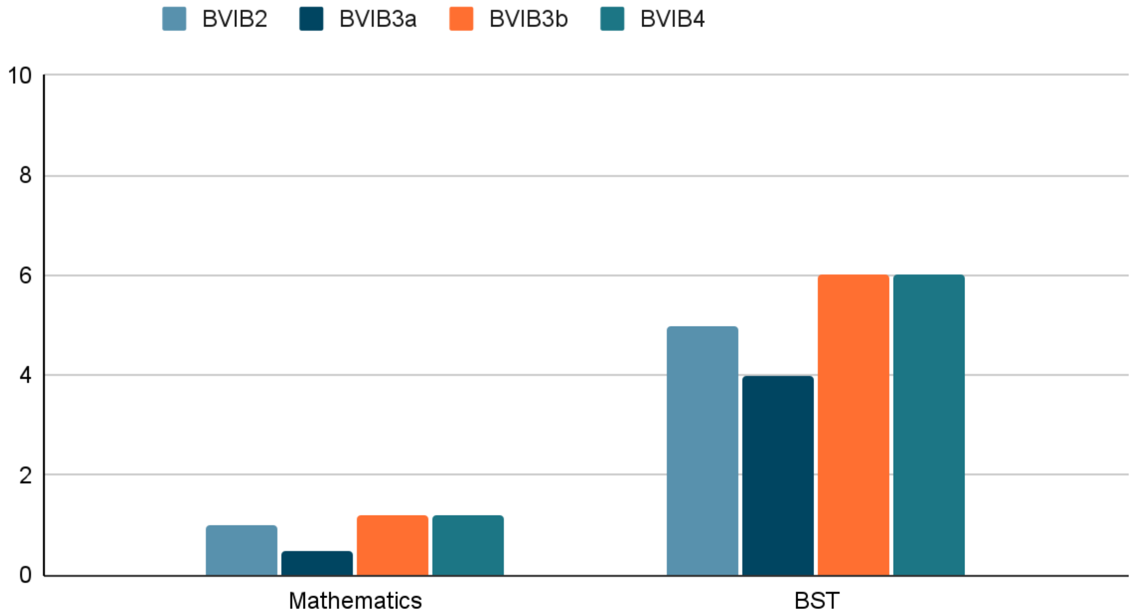
peer interaction of the second BVI in basic 3 were scored 5 and 6 respectively. Following the records of BVIB3a he has low performance in the past when compared with his peers.

The rating of the performance of the pupils in mathematics and BST before the study is presented below. In mathematics, none of them is rated 1 on performance because they don't normally participate in mathematics lessons. Whereas in BST, BVIB3a was rated 4 which is the lowest. BVIB2 was rated 5 while BVIB3b and BVIB4 were rated 6. From the follow up interviews the pupils complained of not seeing the diagrams and illustrations, below are some of their responses:

‘ideas are usually used’
‘sometimes we guess’
‘a lot of the time we are lost during the lessons’

BVIB3a seems to have poor performance, this was also confirmed during the follow up interviews. From the school record, performance of the BVIB3a is lower in other subjects. More information was elicited from the school record. Her performance is very low in other subjects. There is confirmation that the poor pupil has additional issues with concentration in all the subjects, additional special needs was identified.

Figure 3: Performance of BVI in Mathematics and BST before the study



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Vol. 68, 235-250, February, 2025
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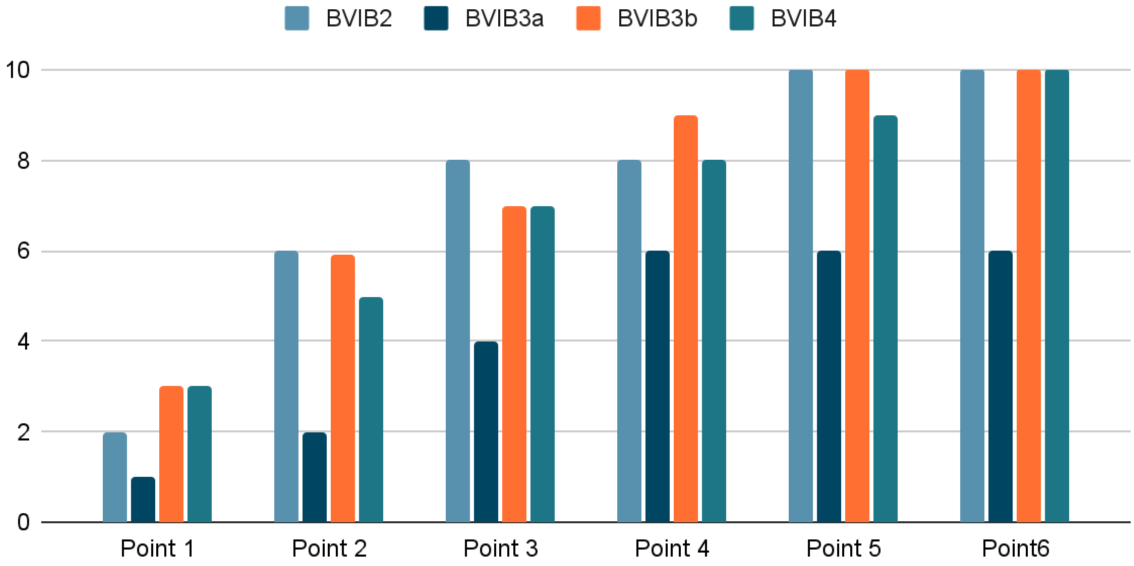
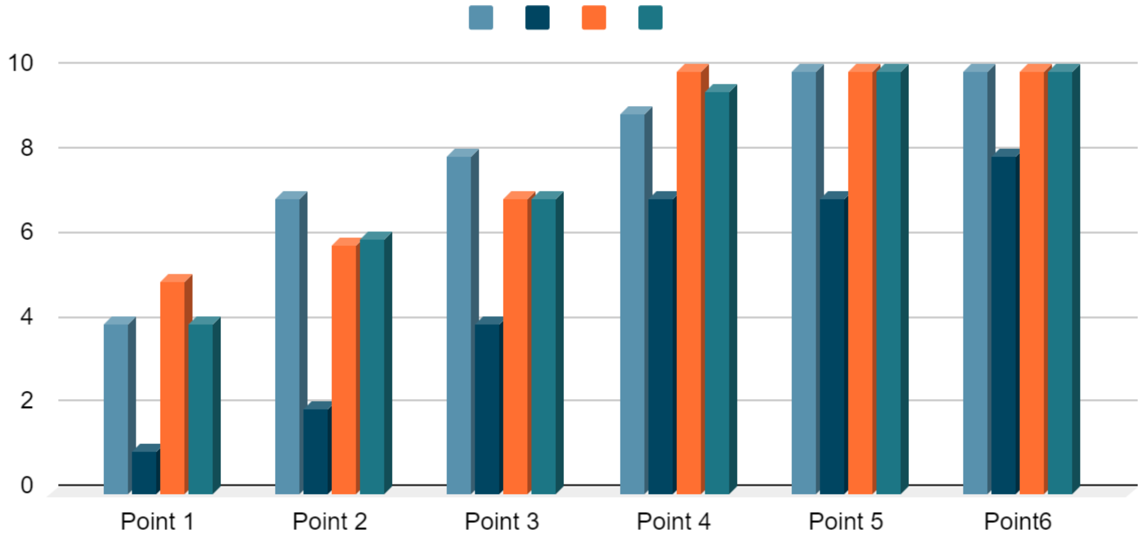
Figure 4: Performance monitored in mathematics at the six points of observations.



Six major points of observations were used in the analysis. Checklist completed by the teacher at the end of the lessons before the termly examinations were used in the analysis. There are three terms in a session and the study was on for two consecutive sessions. Although the teacher recorded many checklists during the teaching every term, they were just used to check the final one submitted. The observations recorded with the videos were also used to validate the scoring of the teachers and where there is discrepancy we follow up in an interview with the teacher and reassess and rescore.

From the chart there is a progressive improvement in the scores of the four pupils throughout the study. At point 1 BVIB2 was scored 2 after intervention was on for a term and later scored 6 followed by 8 by the end of the session, He was scored 8 by the first term of the second session. He became perfect by the second and third term of the second session and scored 10. Similarly, BVIB3b, BVIB4 progressively were scored higher and were finally very good at interpreting and use of information on the tactile diagrams and were scored 10.

Figure 5: Performance in BST at the six points of observations

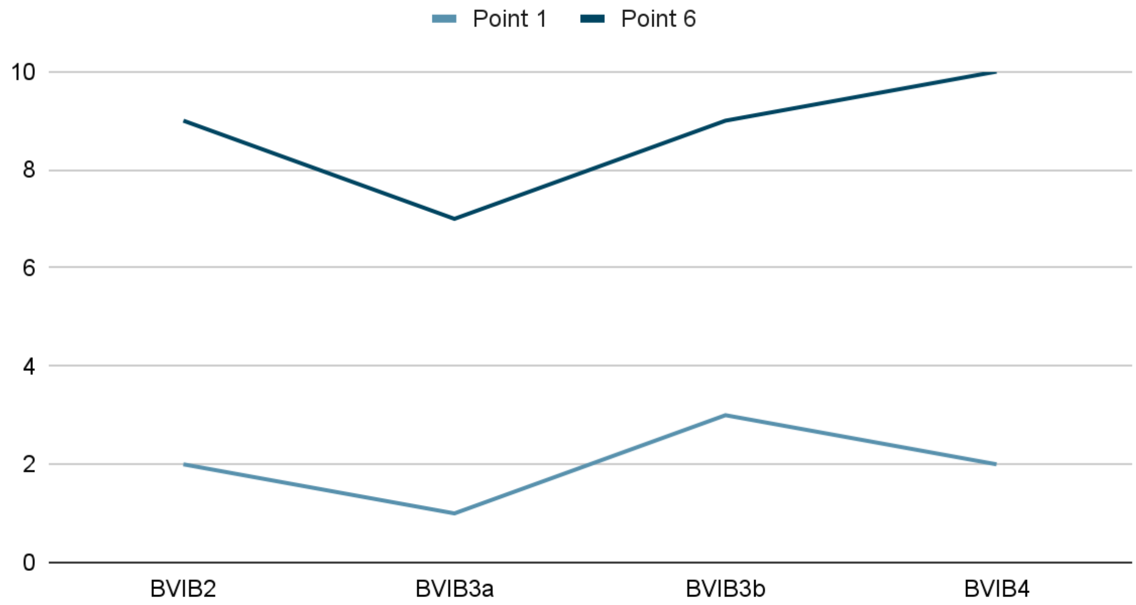


Performance of the four BVI in BST during the study was also scored over 2 sessions. The scoring was like the mathematics score. From the chart BVIB3a has the lowest score but at least improves from 1 to 8, the remaining three BVI were scored 10. From the follow up interviews and cross analysis with the video the BVIB2, BVIB3b and BVIB4 became good and scored 10. The time it takes for the pupils to explore and learn with the tactile diagrams greatly reduced as they are more exposed to it.

We looked for patterns in the behaviour and were analysed especially how it affects their peer interactions and influence on the sighted peers in their classes. The peer interaction is presented below:

The BVIB2 increased from 2 to 9, BVIB3a scores moved from 1 to 7, BVIB3b moved from 3 to 9 while BVIB4 scores moved from 2 to 10. This implies that the peer interactions for all the four pupils were improved.

Figure 6: Presenting the improvement in Peer interactions from points 1 to 6



Altogether, considering observations with the checklist and the recording on the video, the sighted peers were seen moving closer to the BVI and even read the tactile graphics with the BVI. The participation and performance of the sighted peers too were improved. This means that the tactile graphics are also a blessing not only to the BVI but also to the sighted peers.

4. Discussions

Linn and Thier (1975) observed that visually impaired children spend more time exploring their objects than do sighted children. The visually impaired children also engage in more spontaneous conversation than do sighted children. The participation, performance and peer interaction were improved with the use of tactile graphics

These observations are, of course, not surprising. In all other aspects visually impaired children behave similarly to sighted children as identified in earlier research "given knowledgeable, supportive teachers, and with appropriate accommodations such as tactile or auditory materials, students with visual impairments can be as successful and engaged as other students in science and mathematics" (Rule et al, 2011, p. 865). From the findings the BVI performed essentially well when adequate and relevant tactile graphics were supplied during the classroom teaching.

Positive influence was established on the performance of the sighted in the mainstream class with BVI during the follow up interviews with the teachers. This was also reported in the study of Rule et al. (2011) that when teachers are knowledgeable and supportive using appropriate teaching strategies BVI will participate more fully in class activities. In the study Rule mentioned an advantage that sighted peers benefited from using tactile and electronics adaptations with BVI in the class. It was established that given adequate and appropriate resources 10 out of 12 BVI were as successful in mathematics as their peers.

There is clear evidence from research that BVI performed well in STEM subjects and in some cases excelled in them (Adelakun 1994, 2020) The performance of BVIB3a can also be explained by the fact that BVI are different either their features are affected by the onset of the visual impairment and the presence or absence of additional disabilities. This is supported by a finding of Klingenberg, Fosse, and Augestad (2012) that VI are a heterogeneous group with respect to achievement in mathematics.

5. Conclusion

Government policies are mostly directed to provision of equal education to persons with special needs. This is mostly achieved by provision of a resource room for instance and special educational coordinator working in the resource room. How equal is the education that is provided (Doyle 2013) with the support of the resource centre staff who have no adequate knowledge and especially with inadequate resources? This forms the basis for emphasising justice for the BVI and achieving justice will demand adequacy of human and material provision that will make individual capable of pursuing what they choose to do (Snauwaert, 2011) The BVI need adequate provision of alternative forms of access to overcome challenges faced in learning STEM subjects, when this is provided adequate educational opportunity will be achieved. Justice for the BVI will be achieved.

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