THE EFFECTS OF TACTILE DIAGRAM IN BIOLOGY TEACHING IN AN INCLUSIVE CLASSROOM

[1]SARIAT A. ADELAKUN, *Ph.D,* **[2]EVANGELINE U, CHUKUKA,** *Ph.D*, **[3]AMINAT O. ABDULSALAM, [4]MICHEAL O. KEHINDE,** *Ph.D* & **[5]MUSIBAU A. SHITTU**

[1,2,3,4&5]*Federal College of Education (Special), Oyo.*

adelakun.ajibola128@fcesoyo.edu.ng[1] *chukuka.evangeline1331@fcesoyo.edu.ng*[2] *abdul-salaam.aminat1486@fcesoyo.edu.ng*[3] *kehinde.michael1486@fcesoyo.edu.ng*[4] *shittu.musibau2264@fcesoyo.edu.ng*[5]

Corresponding Author: adelakun.ajibola128@fcesoyo.edu.ng +2348035831719.

Abstract

Students with visual impairment are often faced with significant challenges in education, particularly in accessing Science, Technology, Engineering, and Mathematics (STEM) subjects due to their limited vision. These challenges are compounded by factors such as societal ignorance about their abilities, lack of strong educational policies, poor implementation, and inadequate provision of assistive technologies. Students are frequently denied the opportunity to engage equally in subjects of their choice, which may lead to misplaced priorities, school dropouts, and unrealized potential. Other influencing variables include the students' interest, gender, age, and age at onset of visual impairment. Most existing studies rely heavily on conventional teaching methods and the use of inadequate manual diagrams, with little focus on the use of current technologies to produce tactile diagrams in mass for inclusive classrooms. This study therefore investigated the effectiveness of tactile diagrams in improving biology learning among visually impaired students in Nigeria. A quasi-experimental design involving pretest and post-test control groups was used. Sixty students and fifty biology teachers participated, with teachers producing tactile diagrams and pictures for instructional purposes. Data were collected using an achievement test and analyzed with descriptive statistics and one-way ANOVA. The findings revealed that gender, age, type of sight, and age at onset of impairment had no significant effect on the students' ability to recognize tactile materials. Students in the experimental group (both sighted and visually impaired) performed significantly better than those in the control group, with the sighted students performing only slightly higher—an insignificant difference. This confirms the positive impact of tactile diagrams on recognition, understanding, and academic achievement in biology. The study recommends the widespread adoption of tactile diagrams in inclusive science classrooms and calls on education stakeholders to invest in up-to-date tactile production technologies to enhance STEM access for students with visual impairment in Nigeria.

Keyword: Tactile Diagram, Biology, Science Students, Visual Impairment, Sighted Teaching and Learning.

Introduction

People living with visual impairment in Nigeria as other developing nations experience various challenges in the process of education and training. This is more devastating to ones who have flair to study science, technology, engineering and mathematics (STEM) subjects. Children with visual impairment and blindness in Nigeria's secondary and tertiary institution are usually being limited to study non-science relate subjects mainly due to ignorance, lack of STEM resources and poor implementation of policies. Those who insist to study STEM subjects in secondary level may end up to take art subjects in O'level examination/certificate due to unavailability of equipment and materials required to teach and learn practical work in STEM subjects especially in biology which is the focus of the study. Adelakun (2020), observed that even those among them who are offered conditional admission courses are unable to receive their certificate due to their inability to get passing grade in mathematics.

A tactile diagram is a type of image that uses raised surfaces to convey non-textual information such as maps, paintings, graphs, and diagrams to people who are with visual impairment and blindness. Tactile graphics can be seen as a subset of accessible images. They are used to translate images into a tactile language, allowing people especially with visual impairment and blindness to access visual information in works of art, mathematics, science, maps, architectural and other diagrams, and three-dimensional objects and spaces. Tactile diagrams have been found to have a positive impact on the learning outcomes of visually impaired students in biology. These diagrams provide a tactile representation of non-textual information such as pictures, maps, graphs, and diagrams, allowing visually impaired students to access the same information as their sighted peers (pictures of tactile images).

Tactile diagrams therefore, may be a valuable tool in biology teaching, particularly in inclusive or integrated classrooms. Biological science generally deals with abstract concepts which mostly need illustrations through diagrams and pictures. Visual impairment restricts learners with visual disabilities from accessing conventional printed materials. Including them in learning in classroom therefore, needs provision of adapted material in tactile form that may enhance their active participation in biology science classroom learning. Some studies revealed that tactile graphic/diagrammes result to positive outcome in STEM learning. Adefila (2020 and in his study observed that students who were taught biology concepts using tactile graphics performed significantly better in assessments compared to those taught using only oral descriptions. The tactile approach allows learners to build mental images and develop better conceptual understanding of topics like photosynthesis, respiration, and the human circulatory system. Yusuf (2021), in his comparative study, discovered that visually impaired students who learned using tactile materials scored higher in biology tests than those who were taught using conventional audio explanations alone. The study deduced that tactile learning offers multi-sensory engagement, which is a key to meaningful learning for students with visual challenges.

A tactile diagram however, is not automatically meaningful to students with visual impairments unless it depicts identified content or information a learner is meant to access. Biology is one of the core science subjects in secondary schools that deal with the study of living organisms and their vital processes. Many concepts in biology, such as the anatomy of plants and animals, cell structures, and biochemical cycles, are abstract and best understood through visual illustrations and diagrams. The sighted students can easily access diagrams that illustrate vital concepts in biology which learners with visual impairment may experience difficulty unless presented in tactile form. The tactile diagrams in the book include tactile representations of pictures, lines and diagrams, etc., and a visually impaired student can feel these raised lines with brailled labels and/or diagrams to obtain information. Tactile illustrations mainly depend on the texture, size and sequence of the concept. Tactile diagram in biology contain mainly pictures to be touched and embossed pictures and labels help the students with visual impairment to understand the diagrams and access information been described. Different tactile materials used to stimulate the senses of touch, hearing and smell. They provide visually impaired students with the opportunity to engage with abstract concepts through touch, enhancing their understanding and participation in the learning process. However, it is important to consider the design and quality of the diagrams, as well as individual student needs, to ensure their effectiveness in supporting learning outcomes in biology subject. Tactile diagrams may play a crucial role in promoting inclusive and accessibility. However, it is important to note that the effectiveness of tactile diagrams in biology teaching may depend on various factors, such as: the design and quality of the diagrams, Teachers' knowledge and the teaching strategies used, and the individual needs and preferences of the students in an Inclusive setting. Consequently, tactile diagrams are not exact relief reproductions of visual images, but they allow blind and other people with visual impairment to feel and understand the information presented in the image.

Tactile diagrams can be produced using various methods such as thermoform, ink-jet printers, and modified Braille embossers (McCall, 2005). The substrate for tactile diagrams is an important attribute, Different types of substrates can be used to produce a tactile diagram, including rough and smooth plastic, rough and smooth paper, microcapsule paper, Braillon.

Swell Form/ Thermoform Machine (e.g., HumanWare PIAF or Zychem Swell-Form)

View Plus Embosser (e.g., Tiger or Columbia)

The above are examples of some machines and paper for producing tactile diagrammes.

Tactile diagrams are an important tool for making information accessible to people with visual impairment and blindness. They can greatly enhance their independence in education, work, and leisure. Tactile diagrams can be a valuable tool in biology teaching, especially in inclusive or integrated classrooms where students with visual impairments may require non-visual resources to support their learning (McCall, 2005). A ccording to Nwankwo (2017), visual diagrams significantly enhance comprehension, retention, and academic performance in biology by bridging the gap between abstract and concrete learning. Oduyemi and Olayemi (2022) also noted that the absence of tactile instructional materials in many Nigerian public schools significantly limits the ability of learners with visual impairment to comprehend visually intensive subjects like geography and integrated science. As such, the need for structured tactile literacy programs and teacher training is paramount.

According to (Ogunleye, 2023) In biology, the identification of parts, processes, and systems through diagrammatic representation is foundational. Learners are expected to label parts of the respiratory system, distinguish between plant tissues, and interpret food chains and webs. When these concepts are not made accessible through tactile means, students with visual impairment are forced to rely on oral descriptions or rote memorization, which often results in shallow understanding and poor performance (Akinyemi & Adebowale, 2018).

Visual limitation has posed challenges to learners with visual impairment in terms of accessing information that ordinarily, other sighted learner would perceive through visual cues. One of the foundational requirements in biology education is the ability to visualize and interpret diagrams, which are frequently used to represent complex structures like cells, organs, tissues, and ecosystems. For learners who cannot access visual information effectively, alternative modalities must be employed for easy their access to required information especially in biology (Ogunleye, 2023). Zimmermann, (2017). Observed that the solution to this challenge is the use of tactile diagrams, which are raised representations that allow learners to use their sense of touch to perceive visual information Tactile diagrams, when designed appropriately, can provide accessible content, thus promoting inclusion and enhancing cognitive processing for learners with special needs.

According to The Rights of Persons With Disabilities Act (2016), inclusive education is considered to be a system where students with and without disability learn together, and the system of teaching and learning is suitably adapted to meet the learning needs of different types of students. Gender, Age at onset of visual impairment, and nature of sight may also be a barrier in biology science accessibility for students with visual impairment. Ogunleye, (2023) noted that age at onset of visual impairment significantly affect the learners' ability to understand and interpret tactile diagram. Balogun and Aremu (2019), boys are often encouraged to explore tactile resources used in science and technical subjects more than girls, due to prevailing gender stereotypes. Contrarily, Adetoro and Salami (2021), Observed that female learners tend to perform slightly better in tasks involving fine tactile discrimination, possibly due to enhanced finger sensitivity and better attention to tactile detail.

There are also some empirical observations on the impact of age at onset of visual impairment and identification of tactile diagrams and pictures in biology learning. Students who became blind at birth or in early childhood seems to develop tactile exploration better than those with later or late blindness. Adegbola (2020), in a comparative study carried out in secondary schools in southwestern Nigeria, found that learners with early-onset blindness showed significantly higher proficiency in interpreting tactile diagrams compared to those who lost their vision later in life. Early-blind students were more adept at identifying contours, textures, and spatial relationships on raised-line diagrams. This is because they developed compensatory tactile abilities from an early age, whereas late-blind students often struggle to adjust from reliance on visual perception to tactile learning. Also, on the issue of the role of nature of vision in the exploration of tactile diagram, vision may be very germane in tactile diagram identification. Student with sight and low vision may have advantage over the totally blind learner in tactile diagram identification during biology learning. Akinyemi and Balogun (2019) conducted a study comparing students with total blindness and those with low vision in inclusive classrooms and found that totally blind students performed better in tactile tasks when vision was not allowed, such as during blindfolded testing.

Ogunleye, (2023) in his observation stated that the ability to identify tactile diagrams is heavily influenced by the presence of tactile learning training and the type of instructional exposure provided to students. The findings corresponded with Omolewa and Abiona (2021) who carried out a 12-week intervention using Braille-labeled tactile diagrams and 3D teaching aids among learners with visual impairment in a special school in Osun State. Their study revealed that students who underwent the structured training showed a 35% improvement in their tactile interpretation abilities. His result therefore emphasizes the importance of available technology devices to produce enough tactile diagrams and pictures to meet learners' needs in inclusive classroom. To this end, the aim of this study is to find out the impact of tactile diagram in teaching/learning of biology for students with visually impairment in an inclusive classroom. There has been an inadequate access in terms of provision and presentation of adequate tactile equipment, practical and resourceful tactile diagrammes that may effectively stir up positive learning outcome in biology to students with visual impairment in the Nigeria's inclusive educational classrooms.

Statement of the Problem

In an inclusive classroom, all students, including those with visual impairments, have equal opportunities to learn through conventional and adapted means. The use of tactile diagrams in biology teaching in an inclusive classroom may pose challenge to science teachers. In this regard, Students with visual impairment may face a lot of challenges in understanding abstract concepts in the majority of biology topics in the absence of tactile diagrams. Challenges of abstract learning of biology therefore, may poses the major obstacle to these categories of children. Consequently, challenges of engagement and accessibility of practical task in biological science to learners with visual impairment eventually may affect their learning outcome. High cost of technological equipment, government support and empowerment disallow access to tactile images in biology. Nature of visual impairment and gender as well as age at onset of visual impairment may also cause obstacles for effective use of tactile diagram in the learning of biology subject

Aim and Objectives of the Study

The study is aimed at investigating the effect of the tactile diagram in biology teaching students with visual impairment and blindness in an inclusive classroom. While the objectives are to:

i. investigate the impact of nature of sight on ability of visually impaired students to identify Tactile Diagram objects.
ii. explore how gender of biology students who are visually impaired, their nature of sight and age at onset of visual impairment contribute to the Tactile Diagram score in biology.
iii. evaluate the ability of students who are visually impaired to identify and understand biology concepts using the Tactile Diagram.
iv. compare the ability of students with visual impairment and their sighted counterparts as well as the control group in tactile diagramme identification.

Research Hypotheses

The following research hypotheses have been formulated to guide the study:

i. There is no significant main effect of gender on Tactile Diagram score of students with visual impairment in biology
ii. There is no significant main effect of nature of sight on Tactile Diagram score of students with visual impairment in biology.
iii. There is no significant main effect of age at onset of visual impairment on Tactile Diagram identification of students with visual impairment in biology.
iv. There is no significant difference in the Tactile Diagram identification score of visually impaired students, sighted students and those in the control group.
v. There is no significant difference in the Tactile Diagram identification score of visually impaired and those in the control group.

Methodology

Research Design

The research method to be used adopted in this study was pretest and post-test control group quasi experimental research design. This is to compare the achievement of the control and the experimental groups in order to establish whether learning with tactile diagram has any impact in biology science learning.

Population and Sample

Inclusive /integrated secondary school students and their teacher served as the study's sample population. The target population for this study consisted of all secondary school (SSSI) students in the chosen schools. 50 teachers were randomly chosen to br[e trained and produce tactile diagrammes and pictures with or Zychem Swell-Form machine while 60 students were a (randomly sighted and visually impaired ones purposefully) selected from the participated secondary schools. From demographic participation of teachers in the production of tactile diagramme. The sample consists of 50 teachers, with an equal distribution of males (n = 25, 50.0%) and females (n = 25, 50.0%). Teaching experience among the respondents varies. The highest proportion of teachers (n = 17, 34.0%) have between 6–10 years of experience. This is followed by those with 0–5 years of experience (n = 12, 24.0%) and those with 11–15 years (n = 11, 22.0%). The least represented category comprises teachers with 16 years or more of experience (n = 10, 20.0%). Among the teachers, 18 (36.0%) are sighted, while 17 (34.0%) have total blindness, and 15 (30.0%) have low vision. This distribution highlights the presence of teachers in tactile diagram production in biology with varying degrees of vision conditions which may also influence their approach to teaching visually impaired students' biology with tactile diagrams.

The demographic characteristics of the visually impaired students who participated in the experimental study also indicated that Out of the 20 students, 11 (55.0%) are male, while 9 (45.0%) are female. This indicates a slight predominance of male students in the sample. The majority of students (n = 7, 35.0%) experienced the onset of visual impairment between the ages of 11 and 15 years. This is followed by those whose impairment began between 6 and 10 years (n = 6, 30.0%). Additionally, 5 students (25.0%) developed visual impairment at age 16 or later, while the least represented group consists of those who became visually impaired between 0 and 5 years (n = 2, 10.0%). For the sighted students in the study. The sample consists of an equal number of male (n = 10, 50.0%) and female (n = 10, 50.0%) students, indicating a balanced gender representation. The largest proportion of students (n = 7, 35.0%) fall within the 16 years and above category. This is followed by those aged 11–15 years (n = 5, 25.0%). Meanwhile, an equal number of students (n = 4, 20.0%) are within the 0–5 years and 6–10 years age brackets. This distribution suggests a fairly even spread of students across different age groups, with a slight concentration in the older age range.

Consequently, the control group, the sample consists of 12 male students (60.0%) and 8 female students (40.0%), indicating a higher proportion of males in the control group. The majority of students (n = 7, 35.0%) fall within the 11–15 years age group. This is followed by those aged 6–10 years (n = 5, 25.0%). Meanwhile, an equal number of students (n = 4, 20.0%) belong to the youngest age group (0–5 years) and the oldest age group (16 years and above). This distribution suggests a relatively balanced age spread, with a slight concentration in the 11–15 years category.

Research Instrument

The main instrument used for the study will be Snellen chart and referral report charts to screen participants (students) with visual impairment and blindness. 50 structured biological diagram test questions will be drawn on approved standard topics in SS1 biology text book. Two marks will be allotted to each test item previously taught with the use of tactile diagram relating to the topics. The test questions were be given to expert in the field of special education and biological science (the Principal Researcher) for necessary corrections and the validity of the instrument and the reliability of instrument were established using Pearson correlation co-efficiency test-retest method to obtain 0.75 and 0.83 respectively. These indicated the validity and reliability of the test instrument.

Method of Data Analysis

The data for this study was analyzed using the univariance analysis of variance and the independent sample t-test. The hypotheses were tested under the significance level 0.05.

Data Analysis and Interpretation of Results

1. **There is no significant main effect of gender, age at onset of visual impairment and Nature of Sight.**

Table 1: Means, Standard Deviations, and Univariate ANOVA of Sex, Age at Onset and Nature of Sight

Variable		*Sex*				*ANOVA*		
		Male		Female				
YOTE	Nature of Sight	*M*	*SD*	*M*	*SD*	*Effect*	*F*	*df*
0 – 5 Years	Total Blindness	44.00	-	40.0	-	Sex	1.13	1,27
	Low Vision	41.00	4.24	-	-	YOTE	.29	3,27
	Sighted	38.67	3.21	38.0	2.83	NOS	2.43	2,27
						S*YOTE	.62	3,27
6–10 Years	Total Blindness	38.0	11.31	37.25	6.22	S*NOS	.50	2,27
	Low Vision	44.0	44.0	36.75	2.83	YOTE*NOS	.89	6,27
	Sighted	40.0	7.35	38.0	5.09	S*Y*N	.65	5,27
11–15 Years	Total Blindness	41.00	-	39.50	3.53			
	Low Vision	37.67	3.79	37.50	4.95			
	Sighted	39.50	6.36	31.00	-			
16 Years+	Total Blindness	-	-	34.00	.00			
	Low Vision	34.20	1.92	36.50	.71			
	Sighted	34.25	.96	34.00	1.41			

Table 5 presents the results of univariate ANOVA conducted to evaluate the main effect, two-way effect and three-way combined effect of sex, nature of sight and age at onset of visual impairment on ability of students to identify the tactile diagram scores of students in biology.

The ANOVA results show that the main effect of sex on Tactile Diagram scores of students with visual impairment in biology was not statistically significant, $F(1, 27) = 1.13$, $p > .05$. This suggests that there was no meaningful difference in Tactile Diagram scores between male and female students.

The main effect of nature of sight (total blindness, low vision, sighted) was also not significant, $F(2, 27) = 2.43$, $p > .05$. This indicates that the ability to identify Tactile Diagrams was not significantly influenced by whether a student had total blindness, low vision, or was sighted.

Similarly, years of teaching experience did not have a statistically significant main effect on students' Tactile Diagram scores, $F(3, 27) = 0.29$, $p > .05$. This implies that age at onset did not substantially impact students' ability to recognize Tactile Diagrams.

The interaction between sex and age at onset was not statistically significant, $F(3, 27) = 0.62$, $p > .05$. This suggests that the combined effect of a student's sex and their teacher's experience level did not significantly influence their Tactile Diagram scores.

The interaction between sex and nature of sight was also not significant, $F(2, 27) = 0.50$, $p > .05$, indicating that the relationship between sex and students' Tactile Diagram performance was not dependent on whether they had total blindness, low vision, or were sighted.

The interaction between age at onset and nature of sight was not significant, $F(6, 27) = 0.89$, $p > .05$. This suggests that a teacher's experience did not interact with a student's nature of sight to significantly affect their Tactile Diagram scores.

The three-way interaction among sex, nature of sight, and age at onset was not significant, $F(5, 27) = 0.65$, $p > .05$. This indicates that the combined effect of these three variables did not significantly influence Tactile Diagram scores.

The results indicate that neither sex, nature of sight, nor age at onset had a significant main effect on students' ability to identify Tactile Diagram objects. Additionally, none of the interaction effects between these variables were statistically significant. This suggests that students' performance in recognizing Tactile Diagrams was relatively stable across these demographic and instructional factors.

Ho$_2$: There is no significant difference in the Tactile Diagram identification score of visually impaired students, sighted students and those in the control group.

Table 2: ANOVA Results and Descriptive Statistics for Tactile Diagram Identification Scores by Experimental and Control Groups

Groups	*N*		*Mean*		*SD*
Sighted	20		31.50		2.63
Visually impaired	20		28.80		1.48
Control group	20		26.25		1.74
Source	*SS*	*df*	*MS*	*F*	*P*
Between Groups	275.70	2	137.85	34.17	.00
Within Groups	229.95	57	4.03		
Total	505.65	59			

A one-way ANOVA was conducted to examine whether there was a significant difference in Tactile Diagram identification scores among sighted students, visually impaired students, and those in the control group. The results revealed a statistically significant difference in Tactile Diagram identification scores across the three groups, $F(2, 57) = 34.17$, $p < .001$. This indicates that the group a student belonged to significantly influenced their ability to identify Tactile Diagram objects in biology. Sighted students had the highest mean score ($M = 31.50$, $SD = 2.63$). Visually impaired students scored lower ($M = 28.80$, $SD = 1.48$).Students in the control group had the lowest mean score ($M = 26.25$, $SD = 1.74$).

The significant difference suggests that students who received training with Tactile Diagrams (both sighted and visually impaired) performed significantly better than those in the control group, who did not receive the intervention. The results also indicate that sighted students outperformed visually impaired students, which could imply that visual input provides an advantage in identifying Tactile Diagram objects.

Ho$_3$: There is no significant difference in the Tactile Diagram identification score of visually impaired and those in the control group.

Table 3: Results of t-test and Descriptive Statistics for Tactile Diagram identification score by Experimental Group (Visually Impaired) and Control Group

Variable	Visually Impaired			Control Group					
	M	*SD*	*n*	*M*	*SD*	*n*	*t*	*df*	*P*
Tactile Diagram Score	30.75	1.88	19.25	25.5	0.99	20	6.74	38	.00

An independent samples t-test was conducted to examine whether there was a significant difference in the Tactile Diagram identification scores between visually impaired students and those in the control group. The results revealed a statistically significant difference between the two groups, $t(38) = 6.74$, $p < .001$, indicating that the visually impaired students performed significantly better than those in the control group.

Descriptive statistics showed that visually impaired students had a higher mean score (M = 30.75, SD = 1.88) compared to students in the control group (M = 25.50, SD = 0.99). This suggests that the use of Tactile Diagrams had a positive effect on the ability of visually impaired students to identify objects, as they outperformed their counterparts in the control group who did not receive the intervention. The substantial difference in scores further supports the effectiveness of Tactile Diagram-based instruction in improving the learning experience of visually impaired students in biology.

H_{O4}: There is no significant difference in the Tactile Diagram identification score of sighted students and those in the control group.

Table 4: Results of T-Test and Descriptive Statistics for Tactile Diagram Identification Score by Experimental Group (Sighted) and Control Group

Variable	Sighted Group			Control Group					
	M	*SD*	*n*	*M*	*SD*	*n*	*t*	*df*	*p*
Tactile Diagram Score	27.95	0.62	19.15	25.4	0.89	19.15	3.95	38	.00

An independent samples *t*-test was conducted to determine whether there was a significant difference in the Tactile Diagram identification scores between sighted students and those in the control group. The results showed a statistically significant difference between the two groups, $t(38) = 3.95$, $p < .001$, indicating that sighted students performed significantly better than those in the control group.

Descriptive statistics revealed that sighted students had a higher mean score (M = 27.95, SD = 0.62) compared to the control group (M = 25.40, SD = 0.89).

Discussion of the findings

The Table 1 Treated the Null Hypothesis that there is no significant main effect of Gender, Age At Onset of Visual Impairment and Nature of Sight.

The results indicated that neither sex, nature of sight, nor age at onset had a significant main effect on students' ability to identify Tactile Diagram objects. Additionally, none of the interaction effects between these variables were statistically significant. This suggests that students' performance in recognizing Tactile Diagrams was relatively stable across these demographic and instructional factors. This is in line with the findings of Onanuga (2022), who used regression analysis to identify the most influential factors affecting tactile diagram comprehension among students with visual impairment in Lagos State. The findings indicated that the age at onset of blindness was the most significant predictor, followed by the nature of visual impairment, while gender had the weakest effect on tactile learning outcomes. Ogunleye (2023) also highlighted the role of Tactile Diagram-based ability to learn in enhancing their conceptual understanding and object recognition, even for students without visual impairments any condition notwithstanding. The National Policy on Education (FRN, 2014) supported the need to provide appropriate learning resources and accessible content for all learners, despite any condition. CAST, (2011) observed that Tactile diagrams enhance teaching for all learners by incorporating multi-modal learning strategies, combining tactile, auditory, and visual stimuli to cater to diverse learning styles. This result corresponded with (Ogunleye, 2023) who noted that this strategy is consistent with the Universal Design for Learning (UDL) framework, which promotes the design of instructional materials that are flexible and accessible to a wide range of learners from the outset.

Table 2 Examined whether there was a significant difference in Tactile Diagram identification scores among sighted students, visually impaired students, and those in the control group.

The results revealed a statistically significant difference in Tactile Diagram identification scores across the three groups. The significant difference suggests that students who received training with Tactile Diagrams (both sighted and visually impaired) performed significantly better than those in the control group, who did not receive the intervention. Yusuf (2021), finding corresponded with this result in his comparative study, who discovered that visually impaired students who learned using tactile materials scored higher in biology tests than those who were taught using conventional audio explanations alone. The results also indicated that sighted students outperformed the visually impaired students, which could imply that visual input provides an advantage in identifying Tactile Diagram objects. This also is in line with (Ogunleye, 2023) who observed that inclusive instructional materials support all categories of learners, including those with sensory impairments. Kisekka & Mugagga, (2019) also noted in their findings that tactile materials facilitate better retention of information, identification of biological features, and understanding of spatial relationships among biological components.

The 3 treated the null hypothesis that there is no significant difference in the Tactile Diagram identification score of visually impaired and those in the control group.

The result from table 3 showed that the use of Tactile Diagrams had a positive effect on the ability of visually impaired students to identify objects, as they outperformed their counterparts in the control group who did not receive the intervention. The substantial difference in scores further supports the effectiveness of Tactile Diagram-based instruction in improving the learning experience of visually impaired students in biology. Okonkwo, (2017) in his work supported this result that tactile diagramme tools enable visually impaired learners to interpret spatial relationships, textures, and patterns, essential for understanding biology concepts such as the human circulatory system, plant anatomy, or cellular structures.

The table 4 treated the null hypothesis that there is no significant difference in the Tactile Diagram identification score of sighted students and those in the control group.

The result showed that even among sighted students, the use of Tactile Diagrams contributed to improved identification of objects compared to students in the control group who did not receive the intervention. The findings highlight the role of Tactile Diagram-based learning in enhancing conceptual understanding and object recognition, even for students without visual impairments. in line with (Ogunleye, 2023) who observed that inclusive instructional materials support all categories of learners, including those with sensory impairments. Olatunji (2021), observed that incorporating tactile materials in biology lessons helps to engage multiple senses, thus enhancing understanding and memory retention for all categories of learners.

Conclusion

From the results the positive impact use of Zychem Swell-Form machine in the production of tactile diagrams in a given biology contents for the learning of students with visual impairment was felt tremendously in this study. Considering that the various demographic interaction variable did not have significant effect on teaching and learning of biology with tactile diagrammed items. The sighted students' performance over the visually impaired ones was also insignificant. The experimental group with treatment (sighted and visually impaired students performed significantly better than their counterparts in the control group. These also indicate the impact of tactile diagram on achievement of students with visual impairment in biology science identification and recognition. This therefore, implies that tactile diagramme and pictures should be applied in the teaching of biology in an inclusive classroom in Nigeria. Engaging them in the sense of tactual exploration motivates students' interest to preferred subject and gives them sense of interaction with other students. This gives them access to information though identification, internalization and demonstration of learnt concepts. This should however, be collaborative efforts of the teachers, learners and educational stake holders to ensuring that students with visual impairment whose orientation and interest are in STEM have access to technology devices for effective learning. The in-service training on the access to technologies for regular teachers (Sighted and students with visual impairment) will enhance easy access to the teaching of biology science and other STEM courses to students with visual impairment in an inclusive setting in Nigeria.

Contributions to Knowledge

Knowledge has been advanced by this work in the following ways: The expanded the body of the study of teaching/ learning of biology science from descriptive and use of manual diagram to current electronic mass production of needed tactile diagrammes and pictures for effective identification and of a given biology science content. It has succeeded to fill the gap of inadequacy by making diagrams and pictures handy for students to study not only in classrooms but when needed at their disposal. The result of research has served an eye opener to education stake holders, regular teachers as well as parents portraying STEM education for interested students with visual impairment as possible with availability of current technological devices and needed teaching strategies.

Recommendations

Based on the findings of this study, the following recommendations were made:

i. Teachers as well as students of all educational levels should be train and retrained on the production of tactile diagrams for easy access to STEM condition notwithstanding.
ii. Students with visual impairment who have flair to STEM subjects should focus more on their ability than disabilities in achieving their careers of interest alongside with their sighted peers in Nigeria.
iii. Students' ability should be based more on performance rather than visual condition the choice of career.
iv. Tactile diagram machines and other STEM learning accessible technology devices for students with visual impairment should be at the reach of inclusive and integrated schools in Nigeria.

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