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Enhancing Junior Secondary School Students' Mathematics Learning Outcomes in Akwa Ibom State through Virtual Laboratory-Based Instruction

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Abstract
This research examined the impact of virtual laboratory-based instruction on the learning outcomes of J.S.S students in mathematics within Akwa Ibom State. The study had dual objectives, addressing two research questions and testing two null hypotheses. Utilizing purposive sampling, a sample of 92 students from the population of 1,357 in Uyo Local Government area's public junior secondary II schools was selected. The research design was quasi-experimental. For the investigation, two intact classes were utilized. Data was collected using a twenty-item multiple-choice mathematics performance test. This test underwent validation by mathematics education experts. A reliability index of 0.84 was attained through the test-retest method. The experimental group received instruction on perimeter and area calculation for shapes like rectangles, squares, triangles, and trapeziums through virtual laboratory-based methods, while the control group received instruction through traditional physical laboratory-based methods. The two groups were pretested, post-tested and post-post-tested with the instrument to obtain performance and retention scores of the students. Statistical analysis, conducted at a significance level of 0.05, involved calculating the mean, StD, and ANCOVA. The results indicated that students instructed with virtual laboratory-based methods outperformed and retained information better than those taught through traditional physical laboratory-based methods, with statistical significance. As a recommendation, it was suggested that mathematics teachers adopt virtual laboratory-based instruction when teaching plane geometry concepts

Keywords: Plane Geometry, Virtual Lab, Performance, Retention, Technology

Introduction

Due to its practical significance in society, mathematics is mandated as a core subject in secondary education. Its principles permeate through all fields to varying extents, underscoring its interdisciplinary nature across academic disciplines (Hojgaard, 2018). Mathematics development is indispensable for both individuals and nations alike. Its importance extends to personal growth, organizational efficiency, and societal progress, making it a crucial element in various facets of development. Every subject studied in the school has characteristics or features for which they are known. The characteristics or features which any school subject possesses are called the nature or structure of the subject. Mathematics has unique characteristics which distinguish it from every other subject studied in the school. Mathematics has much in common with the natural sciences because it can be studied through investigation, but a close look into mathematics reveals that the difference lies in the method of verifying mathematical claims and scientific claims (Odili, 2006).

The peculiar language and symbolism that mathematics features make it unique from other school subjects. Mathematics is known for the use of mathematical language and symbols which helps to abridge lengthy statements and express them in exact form. The use of symbols makes mathematics to be free of verbosity. The nature of mathematics and the instructional approach which teachers use to teach the subject have made students tag it as a difficult subject. The use of hands-on instructional strategies to teach mathematics therefore becomes something that teachers can resort to. Sreedharal (2008) asserted that laboratory-based instruction can be employed by teachers for teaching. This approach makes the teaching of mathematics active, engaging and interesting. Mathematics is an abstract subject and needs to be learnt by doing rather than by recalling or memorization (George & Charles-Ogan, 2023). The doing of mathematics gives rise to the need for suitable methods and a suitable place. Laboratory-based instruction and mathematics laboratory therefore becomes the right answer to this.

The mathematics laboratory according to Odili (2006) is a place where mathematical activities are carried out and is akin to any other science laboratory. It can also be said to be a place where experiments and mathematical explorations take place. According to Olanrewaju and Anaduaka (2021), engaging in activities within the mathematics laboratory serves as an effective remedy for the evident fear of mathematics among students. George and Charles-Ogan (2023) posited that due to the advancement in technology, mathematics laboratories can be classified into physical mathematics laboratories and virtual mathematics laboratories. Given its status as a fundamental component of secondary education, mathematics instruction and learning ought to lean towards technological integration (Odogwu, 2015). Ensuring effective integration of technology into mathematics education within schools requires readiness on the part of teachers, students, and the learning environment. Physical mathematics laboratories are tangible buildings that contain tangible and concrete manipulatives which can be physically manipulated while the virtual laboratory is an interactive, digital simulation of activities that take place in real laboratory settings. The 21st-century skills are characterized by the use of technology, collaboration, critical thinking, knowledge flexibility, creativity and communication. In this era of digital advancement, it becomes imperative that students and teachers employ the virtual laboratory to activate the teaching and learning of mathematical concepts. This type of instruction can be of benefit to the students who are digital natives. The present-day students do not have the challenge of manipulating any technological gadget, but rather they rejoice at the use of technology.

As the world is going digital, everything around it is also changing by going digital. The world has turned into a global village. Computer devices are seen almost everywhere ranging from offices, financial institutions, churches, markets, the entertainment industry, business centres, schools and even homes. As highlighted by Nwachukwu and Eneh (2018), the realm of education has experienced a transformative shift, significantly altering the responsibilities of educators in imparting academic knowledge to students. Teachers now face increasingly intricate roles, constantly evolving to meet the demands of an education landscape influenced by technology. To cater to the preferences of digitally savvy learners who eschew traditional memorization techniques, educators are expected to embrace technological proficiency. This includes incorporating mathematics software and virtual applications to enhance teaching and learning experiences in mathematics. Mathematics software is an example of specific-purpose application software. The mathematics software is the hub of integrating ICT in the teaching and learning of mathematics. The use of laboratory-based instruction to teach mathematics enables the students to be active during instruction. Engaging students in mathematics laboratory activities justifies the expression of the Chinese adage which says; I hear and I forget. I see and I remember. I do and I understand. Kanu (2020) opined that many online packages and software have been developed to facilitate the use of virtual laboratories. Mathematics is a subject which has found its relevance and application to almost all activities of life. This may suggest why George and Zalmon (2019) opined that mathematics should be taught using innovative methods. Given that there are different teaching methods which the mathematics teacher can employ to teach the subject, it is advisable to uphold the methods that are student-centred, involvement of hands-on activities and use high tech. Laboratory-based instruction is one of the methods that can be used innovatively in this 21st century to carry out the teaching and learning of mathematics in secondary schools. Mathematics education has attracted the attention of all the people in the recent past because of its importance in the era of science and technology, information and communication technology. The society is functioning at a technological level. This has made almost every activity tilt towards the integration and use of technology to carry out operations. There are so many activities that happen online these days due to the use of computers and the internet. Virtual activity encompasses actions, events, or experiences that occur digitally, on a computer screen, or online, rather than in physical reality. It can be described as any temporary or simulated activity facilitated by computer software. Hence, we have virtual images, virtual meetings, virtual science, virtual clinics, virtual learning and virtual laboratories.

A virtual mathematics laboratory is an interactive digital platform designed for learners to conduct experiments akin to those in a conventional mathematics lab. The term "virtual laboratory" is derived from "virtual," signifying simulation, and "laboratory," denoting a space equipped for experimentation and research. Essentially, it offers an

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environment mimicking real-world laboratory settings, facilitating hands-on mathematical exploration through computer-based simulations. The amalgamation of "virtual" and "laboratory" has birthed the notion of a virtual laboratory, characterized by an interactive setting featuring simulated tools for experimentation. Essentially, a virtual laboratory serves as a digital learning space where learners can replicate experiments typically performed in traditional laboratories, utilizing computer-based simulations for exploration and analysis. IGI Global (2024) posited that a virtual laboratory is the implementation of a laboratory using software simulation.

A virtual laboratory is a computer-based setting that replicates the tools and apparatus found in a physical laboratory, allowing for the execution of experiments. It offers students access to experiment materials and tools stored digitally, whether on computers, CDs, or websites, facilitating hands-on learning experiences (Babateen, 2011). The virtual laboratory harnesses computerized models and simulations to substitute conventional lab practices, offering an interactive alternative. Described as an immersive simulation of traditional labs by Ma and Nickerson (2006), a virtual mathematics laboratory serves as a digital platform enabling learners to replicate experiments typically conducted in physical math labs, thereby facilitating hands-on learning experiences. Put simply, a virtual mathematics laboratory serves as a computer-generated replica of traditional lab equipment, designed to supplant conventional math lab practices. The widespread adoption of virtual labs in education is attributed to the emergence of cutting-edge technological devices like computers, iPads, tablets, and Android phones, which captivate student interest during usage. Integration of such technologies in education has opened doors for the creation and advancement of virtual reality resources, promising to elevate practical learning experiences both within and outside school settings. Moreover, these technological innovations offer avenues to diminish or eradicate rote learning in classrooms, fostering an environment conducive to more engaging and purposeful learning encounters. The virtual laboratory holds promise for enhancing teaching effectiveness and facilitating student learning. As a computer-based learning tool, it has been shown to boost students' engagement and enable them to construct experiments and grasp complex concepts with greater ease. This technology thus presents an opportunity for teachers to enhance their instructional methods and for students to improve their learning processes. According to Mahmoud and Zoltan (2009), virtual laboratories are computer-based learning tools that captivate student interest during utilization. They noted that these virtual labs serve as either alternative or additional resources to traditional laboratory setups within educational contexts.

Geometry, an ancient field of mathematics, focuses on the characteristics of space about distance, size, shape, and the relative arrangement of shapes. According to Britannica (2024), geometry encompasses the study of the measurement, attributes, and interconnections among points, lines, and angles. Plane and solid geometrical shapes are all around us. This indicates the importance of geometry in the world. Even though geometry is all around us, students have continued to either skip questions that are related to them in examinations or when attempted, misinterpret the questions to arrive at a wrong answer. This trend becomes worrisome to the researcher, hence the prompt to investigate this study. This study therefore, was conducted to investigate the effect of virtual laboratory-based instruction on the learning outcomes of J.S.S students in plane geometry in Akwa Ibom State.

Statement of the Problem

Mathematics, with its practical applications, has become indispensable in various aspects of daily life, as individuals employ mathematical principles, whether knowingly or unknowingly, to address challenges. This widespread utility likely explains why mathematics is a mandatory component of primary and secondary education. Geometry, a branch of mathematics, specifically focuses on the study of shapes, their characteristics, and the connections between them. Geometrical shapes are found everywhere around us. Students have continued to perform poorly in mathematics due to the instructional approach which students employ to teach mathematical content.

The physical mathematics laboratory was established to see how laboratory activities in mathematics can be employed to engage students meaningfully to enhance their academic performance and retention in the subject. Even though physical laboratories have been established or mounted in some schools, students' academic performance has remained poor in mathematics. Presently we are in the 21st century where the use of technology has taken the order of the day. Most concrete manipulatives that are physically manipulated in the physical mathematics laboratory now have their equivalent virtual manipulatives. Geoboard is a manipulative that can be used to teach geometrical concepts both physically and virtually.

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The inquiry arises as to whether leveraging virtual laboratory-based instruction can bolster the academic achievements and knowledge retention of J.S.S students, who are considered digital natives born in the digital era. With this in mind, the study aimed to explore the impact of virtual laboratory-based instruction on the academic performance and retention of students in plane geometry within Akwa Ibom State.

Aim and Objectives of the Study

This study aimed to investigate the effect of virtual laboratory-based instruction on the performance and retention of J.S.S students in plane geometry. In specific terms, the objectives of the study were to:

1. Determine whether there is any difference between the performance of J.S.S students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction.
2. Ascertain whether there is any difference between the retention of J.S.S students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction.

Research Questions

The two research questions enumerated below were raised and answered.

1. What is the difference between the performance mean score of J.S.S students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction?
2. What is the difference between the retention of J.S.S students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction?

Hypotheses

Two hypotheses which corresponded to the objectives were tested at a 0.05 significant level.

H_{O1}: There is no significant difference between the performance mean score of J.S.S students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction.

H_{O2}: There is no significant difference between the retention of J.S.S students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction.

Methodology

The quasi-experimental research design was employed to conduct this study. This design was employed because the study used intact classes that required no randomization of the subjects. The design involved pretest, control, non-equivalent and non-randomization intact class. This study incorporated two distinct groups: an experimental group and a control group. The experimental group received instruction on the area and perimeter of plane shapes through virtual laboratory-based methods, whereas the control group received the same instruction utilizing traditional physical laboratory-based methods. The study encompassed all 1,357 JSS2 students enrolled in public schools within Uyo L.G.A of Akwa Ibom State. A total of ninety-two (92) junior secondary two students from Uyo L.G.A of Akwa Ibom State made up the sample for the study. Forty-five students were assigned to the experimental group, while forty-seven students were designated to the control group. Two schools were purposively selected from the population, with one school randomly assigned as the experimental group and the other as the control group. Within each school, intact classes were randomly sampled to participate in the study.

A custom-designed assessment tool named the "Plane Geometry Performance Test" (PGPT) was employed for gathering data in this study. The PGPT aimed to assess students' academic proficiency and retention specifically in the field of plane geometry. It comprised an initial segment prompting participants to provide information regarding their school affiliation, grade level, gender, and the allotted time for completing the test. An instruction for all the students to attempt all the questions by circling only one correct answer was conspicuously stated on the instrument. The PGPT comprised twenty questions in a multiple-choice format, with choices labelled A through D. Among these options, only one was correct, while the rest were designed as distractors. Each correct response on the PGPT was awarded five marks, while incorrect answers did not receive any marks. In total, the PGPT carried a maximum score of one hundred marks. A table blueprint was prepared based on the taught mathematics contents (area and perimeter of rectangle, square, triangle and trapezium) to guide in the allocation of questions and marks. The PGPT measured both lower and higher-order Bloom's revised cognitive taxonomy. Table 1 shows the allocation of the test items into Bloom's revised cognitive educational domain.

Table 1: Table blueprint for construction of PGPT

Topic	Remembering	Understanding	Applying	Analyzing	Evaluating	Total
Area of Rectangle	1		1		1	3
Area of Square		2			1	3
Area of Trapezium			1	1		2
Area of Parallelograme	1				1	2
Perimeter of Rectangle			1	1		2
Perimeter of Square		1		1		2
Perimeter of Trapezium	1	1	1	1		4
Perimeter of Parallelograme		1			1	2
Total	3	5	4	4	4	20

The researchers developed two distinct lesson plans utilized by the class teachers to instruct the students in their respective groups. The two lesson plans had the same topics but the difference lies in the type of laboratory-based instruction that was used. The face and content validity of the instrument (PGPT) was determined by two experts in mathematics education from the Department of Mathematics/Statistics, Ignatius Ajuru University of Education, Port Harcourt and Niger Delta University, Wilberforce Island Amasoma. Copies of the instrument were given to these experts to check the content and the extent to which the content was relevant to the investigation. They also checked the clarity of the language to ascertain whether it was phrased for the comprehension of the students at the junior secondary two students. The feedback provided by experts was utilized to refine the instrument before it was administered to the sample group.

Instrument reliability gauges the consistency of measurements over time. In the case of the PGPT, its internal consistency was assessed using the test-retest method. This involved providing copies of the instrument to twenty JSS2 students. This set of twenty (20) students who were not participants of the study were also not taught the concept of area and perimeter of plane shapes before the administration of the instrument (PGPT). Following a two-week interval, the identical PGPT was given again to the same group of twenty students as a follow-up assessment. To prevent memorization of answers, the order of questions was rearranged. Students were instructed to complete all items on the test. The reliability of the instrument was determined using the Pearson Product Moment Correlation, yielding a coefficient of 0.84, signifying its reliability for the study's purposes.

The two groups were first pre-tested using the instrument PGPT before the treatment. The pretest was conducted to ensure homogeneity among the students in the two groups. The instructional session involved educating both groups on calculating the area and perimeter of plane shapes, including rectangles, squares, triangles, and trapeziums. The experimental group received instruction using virtual geoboard manipulatives within the Virtual Mathematics Laboratory, whereas the control group learned using tangible geoboard manipulatives within the Physical Mathematics Laboratory. The teaching was done by the intact class teachers. The intact class teachers were briefly trained by the researchers for one day on the requirements of the research. Following the treatment, a posttest of the PGPT was conducted for both groups. After a two-week interval, a follow-up post-posttest of the PGPT was administered to the same groups. To prevent memorization of test items, the order of questions on the PGPT was randomized. The post-posttest was administered to determine students’ retention of taught concepts. The research questions were addressed descriptively using measures such as mean and standard deviation. To test the hypotheses inferentially, Analysis of Covariance (ANCOVA) was employed, with significance set at the 0.05 level.

Results

Research Question 1: What is the difference between the performance mean score of junior secondary school students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction?

Table 2: Mean and StD on the performance of students taught plane geometry with VLBI and those taught with PLBI

		Pre-test		**Posttest**		**Performance Gain**	
Group	**N**	**Mean**	**StD**	**Mean**	**StD**	**Mean**	**StD**
VLBI	45	30.58	11.42	52.47	10.53	21.89	13.54
PLBI	47	32.51	10.37	46.11	12.49	13.60	6.05

VLBI = Virtual Laboratory-Based Instruction
PLBI =Physical Laboratory-Based Instruction

Table 2 displays the mean and StD of performance differences between students instructed in plane geometry using virtual laboratory methods versus those taught through physical laboratory methods. The findings indicate that students exposed to virtual laboratory-based instruction exhibited a mean performance gain of 21.89 with a StD of 13.54, while those in the physical laboratory-based instruction group had a mean gain of 13.60 with a StD of 6.05. These results suggest that students instructed via virtual laboratories outperformed their counterparts taught in physical laboratories.

Research Question 2: What is the difference between the retention of junior secondary school students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction?

Table 3: Mean and StD on the retention of students taught plane geometry with VLBI and PLBI

		Posttest		Post-Posttest		Retention	
Group	N	Mean	StD	Mean	StD	Mean	StD
VLBI	45	52.47	10.53	71.63	14.36	19.16	10.30
PLBI	47	46.11	12.49	58.57	13.14	12.46	7.11

Table 3 presents the mean and StD regarding the retention differences between students instructed in plane geometry using virtual laboratory methods and those taught with physical laboratory methods. The data shows that students exposed to virtual laboratory-based instruction had a mean retention score of 19.16 with a StD of 10.30, whereas those in the physical laboratory-based instruction group had a mean retention score of 12.46 with a StD of 7.11. These findings indicate that students taught via virtual laboratories retained the material better than their counterparts taught with physical laboratories.

H_{O1}: There is no significant difference between the performance mean score of junior secondary school students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction.

Table 4: Summary of ANCOVA on the performance of students taught plane geometry with VLBI and those taught with PLBI

Source	SS	Df	MS	F	Sig.	η2
Corrected Model	25589.25[a]	2	4264.88	110.83	.00	.71
Intercept	5917.57	1	5917.57	153.78	.00	.55
Pretest	24275.67	1	24275.67	630.86	.00	.06
Group	1676.67	1	335.33	8.71	.00	.42
Error	9773.99	89	38.48			
Total	878230.00	92				
Corrected Total	35363.24	91				

a. R Squared = .732 (Adjusted R Squared = .746)

As depicted in Table 4, the analysis of covariance (ANCOVA) was conducted to assess the significant effect on the performance gap between students instructed in plane geometry using virtual laboratory methods and those using physical laboratory methods. The results indicate a noteworthy distinction in the mean performance scores of students taught via virtual laboratory-based instruction compared to those taught through physical laboratory-based instruction F1, 89 =8.71, p = .00 p< .05, partial eta squared = .42). H_{O1} was rejected at .05 significant level since p-value was less than .05.

H_{O2}: There is no significant difference between the retention of junior secondary school students who were taught plane geometry using virtual laboratory-based instruction and those who were taught using physical laboratory-based instruction.

Table 5: Summary of ANCOVA on the retention of students taught plane geometry with VLBI and those taught with PLBI

Source	SS	Df	MS	F	Sig.	η2
Corrected Model	22084.73[a]	2	3680.79	37.10	.00	.56
Intercept	24785.10	1	24785.10	249.85	.00	.81
Posttest	11382.05	1	11382.05	114.74	.00	.55
Group	5515.19	1	1103.04	11.12	.00	.73
Error	24998.84	89	99.20			
Total	818287.00	92				
Corrected Total	47083.57	91				

a. R Squared = .569 (Adjusted R Squared = .537)

The analysis of covariance (ANCOVA) conducted, as presented in Table 5, examined the significant impact on retention differences between students instructed in plane geometry using virtual laboratory methods and those using physical laboratory methods. The findings suggest a notable disparity in the mean retention scores of students taught via virtual laboratory-based instruction compared to those instructed through physical laboratory-based instruction F1, 89 =11.12, p = .00 p< .05, partial eta squared = .73). H_{O2} was rejected at .05 significant level since p-value was less than .05.

Discussion

Table 2 presents the study's findings regarding the impact of virtual laboratory-based instruction on students' mathematics performance. The analysis revealed that students in the experimental group, instructed in plane geometry concepts using virtual laboratories, outperformed those in the control group, and taught the same material through traditional physical laboratory methods. This outcome aligns with the research of Ityavzua et al. (2019), indicating that virtual laboratory instruction correlates with improved interest and performance in mathematics. Similarly, Sapriati et al. (2023) found that virtual laboratories yielded better results than physical labs in teaching practical skills to students. However, these findings contradict Aleru's (2021) research, which showed higher performance among students taught mathematics concepts using conventional laboratories compared to online alternatives.

Upon statistical analysis, it was found that there existed a notable discrepancy in the performance levels of students who received instruction in plane geometry via virtual laboratory-based methods compared to those who were taught using traditional physical laboratory-based instruction. This finding agrees with the findings of Otiha (2016), Kpemem (2020) and Aleru (2021).

Table 4 outlines the results of the study concerning the influence of virtual laboratory instruction on students' ability to retain mathematical concepts. The analysis revealed that students in the experimental group, exposed to plane geometry instruction via virtual laboratories, exhibited superior retention compared to those in the control group, who were taught using conventional physical laboratory techniques. This result is consistent with Ubakala's (2015) research, which found that students taught with virtual laboratory strategies retained mathematical concepts better than those instructed using conventional laboratory methods. Similarly, Kpemem (2020) corroborated these results, discovering that the utilization of virtual laboratories enhanced students' retention in the experimental group compared to those instructed with physical laboratories in the control group. However, Aleru's (2021) research findings contradicted these conclusions, demonstrating that students taught mathematics concepts through conventional laboratories retained the material better than those instructed with online alternatives. Statistical examination revealed a notable contrast in the retention rates of students who underwent plane geometry instruction via virtual laboratory approaches versus those who received traditional physical laboratory-based teaching. This finding agrees with the findings of Otiha (2016), Kpemem (2020) and Aleru (2021).

Conclusion

Considering the findings uncovered in this study, it was concluded that utilizing virtual laboratory-based instruction to teach plane geometry resulted in enhanced performance compared to traditional physical laboratory-based instruction and implementing virtual laboratory-based instruction for teaching plane geometry led to better retention of the taught concept compared to traditional physical laboratory-based instruction.

Recommendations

It was recommended that:

1. Virtual laboratory should be used to teach students some mathematics topics such as the perimeter and area of plane shapes since these students are digital natives.
2. Virtual laboratory usage should be encouraged to enhance student retention, as it involves engaging with technological devices for manipulation.

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