Effectiveness of Laboratory Method on Enhancing Public Senior Secondary Students' Academic Achievement in Learning Geometric Constructions

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Abstract

This research evaluated the impact of the laboratory learning method on geometric construction achievements among senior secondary school students in the Abeokuta South area of Ogun State, Nigeria. Through a quasi-experimental design, this study engaged 102 mathematics students from Senior Secondary 1 (SS1), comparing the traditional classroom method with innovative laboratory-based instruction. Utilising the Construction Achievement Test (CAT), developed specifically for this research, alongside tailored instructional packages, the study sought to determine significant differences in learning outcomes. Findings, analysed using Analysis of Covariance (ANCOVA), suggested a noteworthy improvement in students' understanding of geometric constructions through laboratory methods, with gender-based differences also observed. Recommendations made include widespread establishment of mathematics laboratories and adoption of laboratory-based learning for practical-oriented topics in mathematics.

Keywords: Achievement, Construction, Laboratory, Learning

Introduction

Mathematics serves as both a practical tool and a foundational pillar of human knowledge, empowering individuals to explore, understand, and enhance the world around them. Its significance cannot be overstated, as it plays a decisive role in numerous fields, including engineering, science, industry, technology, and the arts. Without a strong foundation in Mathematics, no nation can advance scientifically or technologically (Isah & Hamsa, 2023; Omosowon, et al, 2023; Suleiman & Sadu, 2022; Amao & Bakare, 2021). Awodun, et al. (2013) emphasise that mathematics is the cornerstone of science and technology, with diverse applications in every part of the science, technology, and business sectors.

Furthermore, mathematics is essential for equipping individuals with the fundamental skills necessary to navigate the complexities of the modern world (Okigbo & Osuafor, 2008). It is a prerequisite for many professions, including engineering, accounting, medicine, economics, banking, and technology. Consequently, mathematics is a compulsory subject in both primary and secondary education systems, with virtually every institution of higher learning requiring students to demonstrate proficiency in the subject.

Despite its acknowledged significance, challenges such as deficiency of interest and poor performance in mathematics persist among students (Sharma et al., 2019). Factors contributing to this issue include ineffective teaching strategies employed by secondary school mathematics teachers (Ohiri, 2024; Thelma & Morgan, 2023). Nigeria, in particular, grapples with low performance and underachievement in mathematics, as evidenced by studies conducted by various researchers (Awofala & Fatade, 2023; Sa'ad, 2014; Azuka et al., 2013).

Conventional teaching method describes the conservative mode of instruction, which typically involves lectures. This teaching approach is and textbook-Pcentered, exam-focused and teacher-dominated. The primary focus is on retaining and replicating information, concepts, and learning theories. According to Shuchi. (2017), the conventional teaching approach is less student-centered and more teacher-centered, which may eventually impede students' ability to advance both personally and professionally

To address the challenges associated with the teaching and learning of Mathematics, innovative teaching approaches are needed to make mathematics instruction more engaging and cultivate the ability to think critically (Shuchi, 2017; Ukwu, 2008). One such approach is the mathematics laboratory method, which emphasises real-world applications and hands-on learning experiences (Okeke & Okigbo, 2021). This method inspires students to actively engage with mathematical concepts through practical experiments, fostering independent thought and deeper understanding. By moving from the tangible to the intangible, the laboratory approach helps demystify the abstract nature of mathematics, making it more accessible and enjoyable for students (Odili, 2006).

The adoption of innovative teaching methods like the mathematics laboratory approach holds promise for addressing the challenges associated with mathematics education. By providing students with opportunities for discovery and hands-on learning, this approach not only improves their mathematical skills but also cultivates a deeper appreciation for the subject. With proper implementation and support, the mathematics laboratory method has the potential to transform mathematics education and empower students to succeed in an increasingly complex and interconnected world.

The laboratory approach is sequential. The following procedure is mostly taken by the teacher using the laboratory method:

i. Goal of the Practical Work: The instructor makes sure that the students understand the purpose of the practical work, which is an experiment.
ii. Materials and instruments provision: The required materials and instruments are given to the students by the instructor.
iii. Give precise instructions: The instructor clearly outlines the steps involved in the experiment.
iv. Experiment: This is done by the students with the aid of instructional resources led by the teacher
v. Conclude: By the experiment's goal, the students must conclude.

Ale and Adetula (2010) highlighted the potential of the mathematics laboratory as a strategic tool to advance instructional efficiency. This study aims to examine whether the laboratory method of teaching can enhance students' performance in mathematics at the secondary school level, to address cognitive, affective, and psychomotor aspects of learning. Given that mathematics is best learned through active engagement rather than passive reading, it necessitates an appropriate approach and learning environment, such as a dedicated mathematics laboratory and laboratory-based instruction. This activity-based approach allows students to grasp mathematical concepts by actively participating in hands-on activities, aligning with the principles of learning by doing and transitioning from complex to simple concepts.

One area of mathematics that often contributes to junior high school students' poor performance in both internal and external examinations is geometric construction (Chikwe & Ayama, 2016). Geometric construction, a fundamental topic in mathematics, involves creating geometric figures using only a straightedge and compass, adhering to precise rules and techniques. Through construction activities, students explore geometric properties and relationships, refine problem-solving skills, and deepen their understanding of foundational mathematical concepts. The components of geometric construction include basic constructions, triangle constructions, circle constructions, and advanced constructions, each serving to develop students' spatial reasoning and critical thinking abilities.

Beyond its theoretical significance, geometric construction holds practical relevance in various domains, including architecture, technical education, engineering, arts, and design. Students who grasp geometric construction principles are better equipped to think critically, solve problems, and apply spatial reasoning skills in both academic and real-world contexts. By emphasising hands-on learning experiences and active engagement with mathematical concepts, the laboratory-based approach to teaching geometric construction offers a promising avenue for enhancing students' mathematical proficiency and fostering their overall academic success.

Statement of the Problem

Learning becomes enjoyable when the educational needs and aspirations of learners are met throughout the learning journey. Unfortunately, mathematics often evokes negative sentiments among learners, who struggle to grasp its concepts. Poor performance in mathematics amongst secondary school students underscores the challenge of sustaining interest and relevance in the subject. Research has pinpointed teaching methods and a lack of instructional resources as major contributors to students' underperformance in mathematics. Additionally, anecdotal evidence suggests that geometric construction, a crucial aspect of mathematics is often neglected or taught abstractly in secondary school classrooms. Reports from WAEC Chief Examiners further confirm students' inadequate understanding of geometric construction, highlighting the urgent need for effective teaching methods to improve student performance in this area.

Recognising the importance of engaging students in the learning process, this study seeks to explore the impact of utilising mathematics laboratories to teach geometric construction on the academic achievement of senior secondary school students. The laboratory method of teaching offers a hands-on approach that actively engages students in the learning processes, fostering deeper understanding and retention of mathematical concepts. By providing students with tangible experiences and practical applications of geometric construction principles, the laboratory method aims to enhance comprehension and performance in this critical area of mathematics.

The effectiveness of the laboratory method lies in its ability to create an interactive and immersive learning environment where students can explore, experiment, and discover mathematical principles firsthand. Through guided experimentation and collaborative problem-solving, students develop critical thinking skills and gain self-confidence in their mathematical abilities. By bridging the gap between abstract concepts and real-world applications, the laboratory method aims to make mathematics more accessible and relevant to students, ultimately improving their academic outcomes in the subject.

By investigating the impact of mathematics laboratories on students' achievement in geometric construction, this study aims to provide valuable insights into effective teaching strategies for enhancing mathematical proficiency. By leveraging the interactive and experiential nature of the laboratory method, teachers can create dynamic learning experiences that inspire curiosity, engagement, and academic success among students. Through evidence-based research and innovative pedagogical approaches, teachers can empower students to overcome challenges in mathematics and unlock their full potential in the subject.

Research Questions

1. What is the difference in the achievement of students who learnt Construction with laboratory methods and conventional methods?
2. What is the difference between the achievement of male and female students who learnt Construction using laboratory and conventional methods?

Hypotheses

Ho_1: There is no statistically significant difference in the achievement of the students taught Construction using the laboratory methods and conventional methods.

Ho_2: There is no statistically significant gender difference between the achievements of students taught construction using the laboratory method conventional method.

Ho_3: There is no statistically significant interaction between laboratory method and gender on students' achievement in learning Construction.

Methodology

The study utilised a quasi-experimental research design, specifically adopting a pre-test/post-test non-randomised equivalent group design. The target population consisted of SS 1 students from public senior secondary schools in the Abeokuta South area of Ogun State. The sample comprised 102 SS 1 students from two intact classes selected purposively from two senior secondary schools with available technical workshops/Mathematics Laboratories. These schools were chosen based on the presence of the necessary facilities conducive to the study.

To assess students' achievement levels before and after the intervention, the researchers employed a research instrument called the Construction Achievement Test (CAT). The CAT is a twenty-item multiple-choice questionnaire, designed by the researchers, covering knowledge, comprehension, and application levels of the content outlined in the curriculum. The instrument demonstrated good reliability, with an r-value of 0.75, and underwent thorough content validation to ensure its appropriateness for the study.

Both the treatment and control groups were provided with instructional packages, tailored to their respective needs, and supplemented with other essential instructional materials available in the mathematics laboratory. Prior to the implementation of the instructional packages, the CAT was administered to both groups as a pre-test. The intervention lasted for four weeks, after which a post-test was administered to evaluate the effectiveness of the instructional approach.

The data collected from the pre-test and post-test were analysed using descriptive statistics such as mean and standard deviation, as well as Analysis of Covariance to control for any pre-existing variances between the treatment and control groups. This comprehensive approach allowed the researchers to assess the impact of the instructional intervention on students' achievement in geometric construction accurately.

Findings

Research Question 1: What is the difference between students who learnt construction using laboratory methods and conventional methods?

Table 1: Table of Mean achievement scores of students

Method	Mean	Standard. Deviation	N
Laboratory	15.78	2.763	49
Conventional	10.79	1.974	53

The results from Table 1 indicate that students who were taught construction using the laboratory method achieved a higher mean score of 15.78 with a standard deviation of 2.76, whereas those taught with the conventional method achieved a lower mean score of 10.79 with a standard deviation of 1.97 in the post-test scores. This suggests that students performed better when instructed using laboratory equipment compared to the conventional didactic method of teaching. To assess the significance of the results presented in Table 1, hypothesis one was tested.

Research Question 2: What is the gender difference of students who learnt construction using laboratory and conventional methods?

Table 2: Table of Mean achievement scores of male and female students

Gender	Mean	Standard Deviation	N
Male	12.65	2.820	51
Female	13.73	3.935	51

The results from Table 2 indicated that female students achieved a higher mean score of 13.73 with a standard deviation of 3.94, whereas male students attained a mean score of 12.65 with a standard deviation of 2.82 in the post-test scores. To assess the significance of the findings presented in Table 2, hypothesis two was evaluated.

Hypothesis one: There is no statistically significant difference in the achievement of students who learnt mathematics using laboratory methods and conventional methods.

Hypothesis one was tested by comparing the scores of the students who learnt with laboratory methods and those students who learnt with conventional methods using the ANCOVA statistical tool for independent samples. The result is shown in Table 3.

Table 3: ANCOVA Table of Laboratory and Conventional Method

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	767.306[a]	4	191.827	42.858	.000
Intercept	698.471	1	698.471	156.054	.000
Pre-Achievement	9.425	1	9.425	2.106	.150
Method	636.603	1	636.603	142.232	.000
Error	434.155	97	4.476		
Total	18937.000	102			
Corrected Total	1201.461	101			

a. R Squared = .639 (Adjusted R Squared = .624)

It was found that the pretest F-value ($F = 2.11$; $\alpha = 0.05$ $p > .05$) was not significant. This indicates that prior to the treatment; there were no significant differences in the students' levels of construction achievement in the two groups. Therefore, before the treatment, the academic performance of students was consistent across both groups. ANCOVA analysis of the data presented in Table 1 further revealed that the group-related F-value in the post-test was statistically significant, with $F(1, 97) = 142.23$; $p < .05$. Consequently, at the .05 level of significance, the null hypothesis, which posited no significant difference in the achievement of students who learnt Mathematics using the laboratory technique compared to the conventional method, was rejected. This suggests that students who were instructed in Mathematics via the laboratory approach performed better than those taught through the conventional method, with the laboratory approach demonstrating a significantly greater difference in achievement.

Hypothesis two: There is no statistically significant gender difference in the achievement of students who learnt construction using laboratory and conventional methods.

Table 4: ANCOVA Table of gender difference

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	767.306[a]	4	191.827	42.858	.000
Intercept	698.471	1	698.471	156.054	.000
Pre-Achievement	9.425	1	9.425	2.106	.150
Gender	32.651	1	32.651	7.295	.008
Error	434.155	97	4.476		
Total	18937.000	102			
Corrected Total	1201.461	101			

a. R Squared = .639 (Adjusted R Squared = .624)

The ANCOVA analysis of the data presented in Table 4 unveiled a statistically significant group-related F-value in the post-test, yielding F (1, 97) = 32.65; p <.05. Consequently, at the 0.05 level of significance, the null hypothesis, positing no gender difference in the achievement of students who learned construction using laboratory versus conventional methods, was rejected. This suggests a discernible gender gap in the achievement of students who studied geometric construction through traditional versus laboratory methods, with female students exhibiting a preference.

Hypothesis Three: There is no statistically significant interaction between method of instruction and gender on students' achievement in construction.

Hypothesis three was tested by comparing the interaction between methods of instruction with gender on students' achievement in construction using ANCOVA statistical tool for independent sample. The result is shown in table 5.

Table 5: ANCOVA Table of interaction effect on students' achievement in construction

Source	Type III Sum of Squares	Df	Mean Square	F
Corrected Model	767.306[a]	4	191.827	42.858
Intercept	698.471	1	698.471	156.054
Pre-Achievement	9.425	1	9.425	2.106
Method * Gender	87.496	1	87.496	19.549
Error	434.155	97	4.476	
Total	18937.000	102		
Corrected Total	1201.461	101		

a. R Squared = .639 (Adjusted R Squared = .624)

The ANCOVA analysis of the data presented in Table 5 indicates a statistically significant F-value associated with the group, yielding F (1, 97) = 19.55; p <.05. Consequently, at the 0.05 level of significance, the null hypothesis, suggesting no significant interaction between gender and the mode of teaching on students' achievement in geometric construction, is hereby rejected. This suggests a substantial relationship between gender and the mode of instruction concerning students' geometric construction achievement.

Discussion

The study's findings underscore the multifaceted impact of employing the laboratory approach over the traditional method, extending beyond merely enhancing students' conceptual understanding of geometric construction. The rejection of all three hypotheses at the 0.05 level due to their statistical significance highlights the substantive effect of this instructional approach on students' achievement.

These results align with prior research by Anaduaka & Sunday (2021) and Okigbo & Osuafor (2008), who similarly observed enhanced mathematics achievement with the use of a mathematics laboratory. Likewise, Ugwuoti & Mmasi, (2022) and Chibabi et al. (2018) observed the efficacy of teaching biology in a laboratory setting at the senior secondary school level. Consistent findings from Okigbo and Osuafor (2020), Das (2019) further emphasise the benefits of incorporating a mathematics laboratory into classroom instruction, facilitating students' comprehension and internalisation of fundamental mathematical concepts.

However, the results diverge from the findings of Arroyo-Barriguete, et al (2023) who observed varying degrees of gender disparity in mathematics achievement. While Okigbo and Osuofor (2020) did not find a significant gender difference in achievement when using the mathematics laboratory, they did note gender-based disparities when employing specific instructional strategies. Their findings indicated that male students tended to outperform their female counterparts.

Moreover, Table 5 reveals a noteworthy interaction between instructional method and gender, suggesting that the choice of instructional approach influences the achievement gap between male and female students. Female students exhibited greater success with the laboratory method compared to male students, underscoring the importance of curriculum design and instructional strategies in addressing gender-based disparities in learning outcomes.

The significant interaction between instructional technique and gender further underscores the importance of curriculum design and instructional practices in shaping students' learning experiences. By adopting inclusive instructional approaches that cater to divergent learning styles and preferences, teachers can create more supportive and engaging learning environments that foster academic success for all students.

These findings highlight the critical role of teachers in shaping students' academic performance and call attention to the need for equitable and inclusive instructional practices. By leveraging the strengths of the laboratory approach and addressing gender-specific learning needs, teachers can create more conducive learning environments that promote academic excellence for all students, irrespective of gender or upbringing. Further research in this area is warranted to explore additional factors contributing to gender disparities in mathematics achievement and identify targeted interventions to address these discrepancies effectively.

Implications of the Findings

The implications drawn from this study extend beyond the realm of academic achievement to address broader societal perceptions and practices regarding gender and mathematics. It is imperative to challenge the pervasive stereotype that mathematics is a domain reserved for male students, as this misconception perpetuates gender disparities in educational attainment and career opportunities. By highlighting the equal capabilities of female students in mathematics, teachers can foster a more catch-all learning environment where all students feel empowered to excel.

Furthermore, the findings underscore the importance of incorporating practical, hands-on learning experiences, such as laboratory techniques, into mathematics instruction. By engaging students in experiential learning activities that align with real-world applications of mathematical concepts, teachers can enhance students' understanding and retention of key concepts. This approach not only promotes academic achievement but also cultivates critical thinking skills and problem-solving abilities essential for success in an increasingly complex and dynamic world.

In addition to its implications for classroom practice, the study underscores the need for on-going efforts to address gender-based disparities in STEM fields. By debunking the myth that mathematics is a male-dominated domain, teachers can encourage more female students to pursue STEM-related studies and careers, thereby fostering greater diversity and innovation in these fields. Moreover, by promoting gender equity in STEM education, we can harness the full potential of all students to contribute to scientific and technological advancements that benefit society as a whole.

Moving forward, teachers, policymakers, and other stakeholders need to collaborate on initiatives aimed at promoting gender equity and inclusion in mathematics education. This includes implementing evidence-based strategies to support female students' participation and achievement in mathematics, as well as addressing systemic barriers that may hinder their progress. By encouraging a helpful and inclusive learning environment where all students feel esteemed and empowered, we can unlock the full potential of every individual to excel in mathematics and beyond.

Conclusion

Moving forward, it is imperative to continue exploring innovative instructional strategies and interventions to address persistent challenges in mathematics education, including gender-based disparities. Concerted exertions between researchers, teachers, policymakers, and other stakeholders are essential to designing evidence-based interventions that encourage equity and excellence in mathematics learning.

This study contributes valuable perceptions into the potential of the laboratory approach to enhance students' achievement in geometric construction. By leveraging the strengths of hands-on, experiential learning, teachers can empower students to develop a profound understanding of mathematical concepts and achieve academic success. However, addressing gender-based disparities in mathematics achievement entails a multifaceted approach that considers the complex interplay of instructional practices, curriculum design, and individual learning needs. Through on-going research and collaboration, we can work towards fashioning more comprehensive and equitable mathematics learning environments that support the success of all students.

Recommendations

In light of the findings and benefits associated with the laboratory method, several recommendations emerge to enhance mathematics education and promote student achievement. Firstly, there is a compelling argument for expanding the use of the laboratory approach across a wide range of mathematical topics. By incorporating hands-on, experiential learning experiences into mathematics instruction, teachers can facilitate deeper conceptual understanding and foster greater engagement among students. This shift towards a more active and practical approach to teaching mathematics has the potential to yield significant improvements in students' academic performance and overall learning outcomes.

Moreover, it is essential to ensure equitable access to the benefits of the laboratory method for all students, irrespective of gender. Efforts should be made to encourage inclusivity and diversity in mathematics education by providing equal opportunities for male and female students to engage with the laboratory approach. This may involve implementing targeted interventions to address gender-based disparities in participation and achievement, as well as promoting a helpful and all-encompassing learning environment where all students feel treasured and empowered to succeed.

Furthermore, there is a need for increased investment in the development and provision of mathematics laboratories in schools. Just as science laboratories are considered essential for science-related courses, mathematics laboratories should be recognised as indispensable for the effective teaching and learning of mathematics. Government agencies, educational institutions, and other stakeholders should collaborate to ensure that adequate resources are allocated to the establishment and maintenance of mathematics laboratories in schools, particularly in underserved communities.

Additionally, on-going professional development opportunities should be made available to secondary school mathematics teachers to enhance their knowledge and skills in using the mathematics laboratory. Seminars, workshops, and training sessions focused on effective instructional strategies and best practices for integrating the laboratory method into mathematics instruction can provide teachers with the necessary support and guidance to implement this approach successfully.

Finally, pre-service teacher education programmes should integrate training on the use of the mathematics laboratory into the curriculum for mathematics student teachers. By equipping future teachers with the knowledge and skills to effectively utilise the laboratory method in their teaching practice, teacher education programs can help ensure that the benefits of this approach are sustained and expanded in the years to come. Through these concerted efforts, we can strive towards a more innovative, inclusive, and effective approach to mathematics education that empowers all students to succeed.

Suggestion for further studies

Building upon the insights gained from this study, it is advisable to replicate the research in diverse settings to validate the findings and ascertain their generalisability. Conducting similar investigations in other geographic locations or educational contexts would provide treasured insights into the broader applicability and effectiveness of the laboratory mode of instruction in enhancing students' geometric construction skills. By comparing results across different regions or school settings, researchers can identify common trends or variations and gain a more comprehensive understanding of the impact of the laboratory approach on student learning outcomes.

Moreover, future research endeavors could focus on developing comprehensive implementation plans for integrating mathematics laboratories into secondary school instruction. This entails not only establishing physical laboratory spaces but also designing curriculum frameworks, instructional materials, and teacher training programmes tailored to the unique needs and challenges of mathematics education. By systematically addressing the logistical, pedagogical, and organizational aspects of mathematics laboratory implementation, teachers can maximize the benefits of this innovative teaching approach and create a conducive learning environment for students.

Furthermore, it is essential to explore the broader implications of using mathematics laboratories in secondary school mathematics instruction and learning. This entails conducting longitudinal studies with large sample sizes across multiple regions to assess the long-term effects of mathematics laboratory use on students' mathematical performance, attitudes, and career aspirations. By tracking students' progress over time and examining any disparities between public and private school settings, researchers can identify strategies for encouraging equity and excellence in mathematics education and inform policy decisions aimed at improving educational outcomes for all students.

Additionally, future research efforts could delve into the specific instructional practices, pedagogical strategies, and learning experiences that contribute to the success of mathematics laboratory programs. By conducting qualitative inquiries, classroom observations, and interviews with teachers and students, researchers can gain insights into the factors that facilitate the effective implementation and utilization of mathematics laboratories. This qualitative data can complement quantitative findings and provide a more nuanced understanding of the mechanisms underlying the observed effects of the laboratory mode of instruction on student learning and achievement.

Conducting further research on the impact of mathematics laboratories on secondary school mathematics instruction and learning holds great promise for advancing our understanding of effective teaching practices and improving educational outcomes. By building upon the findings of this study and exploring new avenues of inquiry, researchers can contribute to the ongoing efforts to enhance mathematics education and empower students to succeed in the 21st century.

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