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Improving Students' Achievement in Geometry Through Laboratory-Based Instructional Methods in Jalingo Metropolis, Taraba State, Nigeria

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ABSTRACT

This study investigated the effect of laboratory-based instructional methods on students' achievement in geometry within the educational context of Jalingo Metropolis, Taraba State, Nigeria, over six weeks. Recognising the potential of hands-on, experiential learning approaches in mathematics education, particularly in geometry, this research explored the effectiveness of laboratory-based instruction in enhancing student performance. Guided by three research questions and hypotheses, the quasi-experimental research design was employed on a sample of 160 Upper Basic II students, through pre-and post-test assessments. The Geometry Achievement Test (GAT) with a reliability index of 0.91 for the GAT, determined using the K-R20 method, was used for data collection. The mean and standard deviation statistics were employed to answer the three research questions, while covariance (ANCOVA) analysis was employed to test all hypotheses at a significance level of 0.05. The study found a significant improvement in geometry achievement among students exposed to the laboratory-based method, with 56% of the achievement score variance attributed to this method. Additionally, it identifies a noteworthy difference in achievement scores between male and female students taught geometry using the laboratory-based approach, with a significant interaction between the teaching method and gender. These findings underscore the potential of laboratory-based instructional methods to improve student engagement and comprehension in geometry, particularly in educational settings that face similar resource and teaching challenges. By fostering hands-on learning and critical thinking, this approach could be an effective strategy for enhancing math achievement and supporting curriculum development in Nigeria and comparable regions. Overall, the study contributes valuable insights to the discourse on innovative pedagogical practices in mathematics instruction, offering guidance for educators and policymakers aiming to improve mathematics education in similar contexts.

1. INTRODUCTION

The traditional lecture method has been the mainstay in mathematics teaching for many years. Based on direct instruction, this approach has the teacher directing students through mathematical ideas, problem-solving strategies, and theory application in an organized manner. However, more than thirty years ago, it was recognized that the traditional lecture method alone might not be the most effective way to help students internalize and apply mathematical concepts (Lugosi & Uribe, 2020). Chickering and Gamson (1991) argued that learning is fundamentally different from passively observing, highlighting why a lecture-based method may not fully support mathematical understanding. Students tend to retain little when they merely sit and listen in class.

The President’s Council of Advisors on Science and Technology (2012) emphasizes that active learning methods enhance retention and critical thinking skills in STEM education. Active participation, as Stanberry (2018) suggests, is essential for achieving better learning outcomes, particularly in mathematics, where interactive learning fosters deep understanding. Most studies, including those by Lugosi and Uribe (2020), confirm that active student participation is crucial, contrasting with the limitations of lecture-only methods and enhancing persistence among students pursuing STEM disciplines. Therefore, diverse instructional methods and appropriate resources are essential for achieving learning goals in mathematics (Azid et al., 2020).

One subject that especially benefits from hands-on, experiential methods is mathematics, which otherwise poses challenges for both teaching and learning when taught solely through theoretical instruction. Hwa (2018) notes that engaging, realistic methods make mathematics instruction more accessible and interesting, leading to better student outcomes. When students experience mathematical concepts directly—whether through physical models or problem-solving—they tend to internalize and understand these concepts more thoroughly (Rach & Ufer, 2020).

Laboratory-based instructional methods provide one such active approach, promoting student engagement and comprehension through hands-on activities. In geometry, these methods can include using geometry kits for constructing shapes, digital modelling software to visualize geometric transformations, or group problem-solving exercises that require students to apply geometric theorems to real-world scenarios. For example, Srinivasa (1978) proposed mathematics laboratories as a solution for concept formation, allowing students to interact with tangible objects, which helps abstract ideas take shape and improves comprehension. Such methods have been linked to improved engagement and achievement, particularly in studies by Agwagah (1997) and more recently by Anakpua et al. (2020) and Perchiniak et al., (2023), who observed that laboratory-based instruction enhances problem-solving and critical thinking.

In Nigeria, however, challenges such as limited classroom resources, large class sizes, and insufficient teacher training hinder the implementation of active learning methods. Many schools lack the infrastructure needed for hands-on activities, and teachers often have limited access to resources or training in laboratory-based techniques, particularly in geometry. These limitations underscore the need for adaptable and resource-efficient strategies that can promote meaningful learning even in under-resourced settings.

Geometry specifically was chosen as the focus of this study due to its foundational role in developing spatial reasoning skills, which are crucial for students’ broader STEM competencies. Mastery of geometric concepts fosters critical thinking and problem-solving skills, making it an essential area of focus for enhancing overall mathematical ability. Thus, this study investigates how laboratory-based instructional methods impact students' achievement in geometry in the Jalingo metropolis, Taraba State, Nigeria, aiming to identify strategies that can address the specific educational challenges in this context.

2. LITERATURE REVIEW

In Ezeliora's (2001) perspective, a science laboratory is identified as a workspace where scientific activities are conducted or where science is practised within a conducive environment. Omiko (2007) further characterises a laboratory as a designated space, be it a room or building, or a specific time limit, furnished and allocated for practical or experimental studies. Omiko emphasises the laboratory's significance as the core of a robust scientific programme, enabling students in the school to gain experiences aligned with the objectives of scientific literacy. This underscores the essential role of a well-equipped laboratory in secondary schools, as posited by Omiko, where practical activities are essential for imparting science process skills to learners and ensuring effective science teaching and learning. Hence, the laboratory-based teaching method encompasses instructional strategies focusing on students' hands-on experiences through experimentation, fieldwork, and activity projects.

The laboratory-based instruction, according to Joshi (2008), is a special teaching method and a crucial component of successful science education. With this method, teacher dominance is reduced, while students are encouraged to conduct experiments to extract scientific rules and concepts. Richard (2009) quoted Landauer, highlighting that the implementation of the laboratory-based strategy closely resembles the hybrid approach. This hybrid approach amalgamates various methods related to students' conceptual adoption, incorporating expository learning, cooperative inquiry, solution workshops, and virtual workshops utilising computer-internet interfaces. The strategy encompasses discussions about computer technology within the context of laboratory-based learning strategies. Students interact directly with their peers and teachers in a well-designed laboratory, allowing for effective monitoring, assessment, and enhancement of learning (Ojediran et al., 2014). Ngala (2019) observed that the varied activities within a laboratory-based instructional method collectively contribute to practical exercises, fostering engagement within and beyond the classroom. These activities may involve individuals, small groups, or the entire class, providing a dynamic and interactive learning experience. Laboratory-based strategy, according to Dafid et al. (2022), is a learning strategy that allows students to empirically practice cognitive, affective, and psychomotor abilities using laboratory facilities.

Some academics commonly designate this approach simply as "practicals." According to Tambo (2012), laboratory-based teaching is distinctly characterised as an interactive learning process where, under the guidance of an instructor, students explore various facets of a subject. Tambo emphasises that the central aim of this methodology is to address specific challenges or provide answers within the educational sphere. Echoing this sentiment, Nekang (2016) describes the laboratory-based instructional method as a pedagogical tool guiding students through practical experiments, thereby cultivating skills in observation, tactile exploration, approximation, and estimation. Fundamentally, the laboratory-based instructional method functions as a conduit for imparting learners with both generic and scientific process skills, equipping them to tackle real-world problems. This empowerment stems from the active involvement of learners in constructing knowledge during the teaching-learning process.

Relatedly, Dienye and Gbamanja (1990) observe that the laboratory-based teaching method adopts a dual approach, incorporating both exercise and experimental methods. This dual-pronged strategy, facilitated by one or more instructors, proves invaluable in the realm of science education. The experimental approach encourages students to seek information through hands-on experimentation, necessitating careful observation and data interpretation. These processes embody qualities of inquiry, investigation, and grappling with the unfamiliar, catering to diverse learning preferences and fostering a holistic educational experience.

For centuries, laboratory-based instructional methods have been the benchmark for training practical skills. To put theoretical knowledge into practical situations, laboratory-based instructional methods are needed. However, most secondary school laboratories are assigned to physics, chemistry, and biology, each with specialised technicians. It is rare for mathematics students in Nigeria to use the scientific laboratory because mathematics is not considered a practical science. According to Hernández-de-Menéndez et al. (2019), even teachers do not understand the need for a laboratory to teach mathematics. This misconception notwithstanding, the use of laboratory-based instruction in mathematics lessons cannot be underestimated. Students acquire an in-depth understanding of mathematical topics. They are better prepared for success in both academic and real-world situations when laboratory-based methods of instruction are incorporated into mathematics learning. This approach to learning is comprehensive and effective (OpenAI, ChatGPT (3.5), 2024). Ngala (2019), citing Udondu (2009) and Omiko (2015) emphasises the advantages of employing the laboratory-based teaching approach, which encompasses improving comprehension of science and technology, nurturing problem-solving abilities, promoting the emulation of scientists, and cultivating enthusiasm, attitudes, and values towards science.

There is a plethora of research on the benefits of laboratory-based education. Ngala's (2019) research findings indicate that employing laboratory-based teaching approaches improves the development of fundamental science process skills among high school students studying biology. Ngala advised that instructors in secondary education institutions utilize this method, particularly when covering topics that necessitate hands-on activities, to enhance students' acquisition of science skills in biology effectively. Similar findings were made by Anakpua et al. (2020), who showed that integrating mathematics laboratories into the teaching of mathematics promotes student-centred learning and improves problem-solving abilities. One of their suggestions is that teachers of mathematics use a variety of teaching strategies and educational materials to help students overcome the abstract character of the subject and improve their performance. In their study conducted in 2020, Rathod and Amini found that an instructional approach focused on a mathematics laboratory proved effective in aiding eighth-grade students' understanding of the concepts taught within the quadrilateral’s unit of mathematics.

According to Dafid et al. (2022), learning linear geometry in a laboratory setting is a more effective approach. Bindu and Ramakrishna's research, conducted in 2023, revealed that the conventional method of teaching and learning mathematics content delivery for eighth-grade students was comparatively less successful in fostering the development of mathematical concepts compared to the laboratory-based approach. The laboratory method fosters scientific thinking in students and not only gets their attention but also improves their performance and engagement (Jepkosgei, 2023). It also helps students acquire the abilities they need for further study and research. According to the study, teachers should incorporate the laboratory technique into their lesson plans to guarantee that students are more engaged and involved in mathematical activities. It also emphasises how important it is for teachers to be trained in properly applying the laboratory technique.

The theoretical anchor for laboratory-based methods in teaching mathematics often draws upon the principles of constructivism and hands-on learning. Elliott et al. (2000) defined constructivism as an approach to learning that asserts individuals actively construct their knowledge, and reality is shaped by the experiences of the learner. According to McLeod (2024), constructivism is a learning theory that emphasises how learners actively shape their cognition. Learners gather and process information, create mental models, apply new information to preexisting frameworks, and actively reflect on their experiences. Expanding on constructivist concepts, Arends (1998) suggests that constructivism advocates for learners to personally construct meaning through experiences, where meaning is shaped by the interplay between prior knowledge and new encounters.

In the context of mathematics education, laboratory-based methods provide students with opportunities to engage directly with mathematical concepts through experimentation, exploration, and discovery. These methods emphasise active participation, inquiry, and problem-solving, allowing students to build their understanding of mathematical concepts through first-hand experiences. The impetus for this study was provided by the aforementioned, which prompted an investigation into the effect of laboratory-based teaching methods on geometry achievement among secondary school students in the Jalingo metropolis of Taraba State, Nigeria.

Research Questions

The study was guided by the three research questions, as follows.

RQ 1: To what extent does the laboratory-based method affect Upper Basic II students' achievement in geometry?

RQ 2: What is the difference between the Upper Basic II male and female students' achievement in geometry when the laboratory-based method is used?

RQ 3: What is the interaction effect of the method of teaching and gender on Upper Basic II students' achievement in geometry?

Research Hypotheses

The study was guided by the three hypotheses, which were tested at a 0.05 level of significance.

$H0_1$: The laboratory-based method has no significant effect on Upper Basic II students' achievement in geometry.

$H0_2$: There is no significant difference between Upper Basic II male and female students' achievement in geometry when the laboratory-based method is used.

$H0_3$: There is no significant interaction effect of the method of teaching and gender on Upper Basic II students' achievement in geometry.

3. METHODS

This study adopted a quasi-experimental design, employing a non-equivalent pre- and post-test approach. Due to the use of intact classes, complete randomization was impractical; hence, pre-test results were used to establish baseline equivalency between groups. The sample was divided into two groups: Group A served as the experimental group, receiving instruction through the laboratory-based method, while Group B acted as the control group, following a conventional approach. Initial assessment via pre-testing established a baseline for both groups and after six weeks of instruction on specific geometric concepts, a post-test measured achievement, serving as the dependent variable. Gain scores were calculated based on post-test results to evaluate the intervention's effectiveness.

Teacher Training for Intervention: To ensure consistent implementation of the laboratory-based method, teachers in the experimental group participated in preparatory training sessions before the intervention. These workshops introduced teachers to hands-on tools, such as geometry kits, and guided structuring of group activities to maximize student engagement. The training sessions also covered techniques for facilitating student-led experiments and collaborative problem-solving exercises, equipping teachers with practical skills for fostering an interactive learning environment. By the end of the training, teachers were familiarized with all components of the methodology instructional Package (MIP) designed specifically for this study.

Population and Sample: The study population comprised 6,698 Upper Basic II students within the Jalingo metropolis of Taraba State, Nigeria, drawn from 25 schools in the area. This population included 3,612 males and 3,086 females. Upper Basic II students were selected for their stable academic position, as Upper Basic I students are newly admitted and Upper Basic III students are in their final year. The sample comprised 160 Upper Basic II students from two schools purposefully chosen based on criteria such as the mathematics teachers' qualifications (bachelor's degree in mathematics education) and at least three years of teaching experience. The schools were then randomly assigned to either the experimental or control group.

Methodology Instructional Package (MIP): The methodology instructional package (MIP) included lesson plans and curriculum materials for both groups, though each utilized different instructional methods. The control group followed traditional classroom activities, while the experimental group used the laboratory-based approach provided by the MIP. In the laboratory-based setup, students engaged in hands-on exercises, including geometric model construction, experiments, and interactive laboratory tasks, all designed to deepen their understanding of geometric concepts. The instructional period for both groups consisted of ten 40-minute lessons on specific geometry topics.

Geometry Achievement Test (GAT): Data on student achievement were collected using the Geometry Achievement Test (GAT), a fifty-item multiple-choice assessment with four options per item. The GAT included a range of problem-solving and conceptual questions covering angles, shapes, theorems, and geometric transformations, all chosen to assess practical geometry skills. Questions required students to apply knowledge of geometric properties in both abstract and real-world scenarios, evaluating their understanding of spatial relationships, measurement, and logical reasoning. Three experts in mathematics education, science education, and educational measurement reviewed the GAT for face, content, and construct validity. Item analysis using the Kuder-Richardson Formula 20 (K-R20) confirmed a high-reliability index of 0.91.

Data Analysis: Data collected through the GAT were categorized into pre-test and post-test scores for both experimental and control groups. Further analysis was conducted based on gender, as it was considered a moderator variable in the study. Mean and standard deviation statistics were used to answer the research questions, while covariance (ANCOVA) analysis was employed to test all hypotheses at a 0.05 significance level. ANCOVA was specifically used to adjust for initial baseline disparities due to intact class sampling and to control for covariate effects, enabling accurate comparison of achievement outcomes between the two groups.

4. RESULTS

Research question one

To what extent does the laboratory-based method affect Upper Basic II students' achievement in geometry?

Table 1. Mean Achievement Scores of Students in the laboratory-based method compared to the conventional lecture method.

Group	N	Pretest		Post-test		Mean
		mean	std. dev	mean	std. dev	gain
L-B Grp	93	9.19	3.68	24.15	4.87	14.96
Control Grp	67	8.61	2.63	14.63	3.28	6.02
Mean difference		0.58		9.52		8.94

L-B = Laboratory-based method

Control Grp = conventional lecture method

Table 1 shows that the experimental group taught geometry using the laboratory-based method had a pretest mean score of 9.19 with a standard deviation of 3.68, while the control group taught using the conventional lecture method had a pretest mean score of 8.61 with a standard deviation of 2.63. The difference between the pretest scores of the experimental group and the control group is 0.58. After the effect of the pretest has been statistically removed, the posttest mean score of the students taught using the laboratory-based method stands at 24.15, while that of their counterparts taught using the conventional lecture method is 14.63. The standard deviation scores of the two groups indicate that the data sets in the two groups exhibit a reasonable degree of consistency. The difference between the post-test mean score of the students in the two groups is 9.52 and in favour of the group taught geometry using a laboratory-based method.

The mean gain (that is, the difference between the pretest and posttest scores) of students taught using the laboratory-based method is 14.96, while that of those taught using the conventional instruction method is 6.02. The mean gain shows that the laboratory-based group gained higher than the control group by 8.94 units. Therefore, it can be inferred that the laboratory-based method was highly effective in enhancing students' performance in geometry.

Research question two

What is the difference between the Upper Basic II male and female students' achievement in geometry when the laboratory-based method is used?

Table 2. Mean Achievement Scores of male and female students in the laboratory-based method

Gender	N	Pretest		Post-test		Mean
		mean	std. dev	mean	std. dev	gain
Male	42	8.98	4.23	25.31	5.13	16.33
Female	51	9.37	3.19	23.19	4.47	13.82
Mean difference		0.39		2.12		2.51

Table 2 shows that male students had a pretest achievement mean score of 8.98 with a standard deviation of 4.23, while female students had a pretest mean score of 9.37 with a standard deviation of 3.19. The difference between the pretest achievement scores of the experimental group and the control group is 0.39. After the effect of the pretest has been statistically removed, the posttest mean score of male students stands at 25.31, while that of their female counterparts is 23.19. The standard deviation scores of the male and female students indicate that the data sets in the two groups exhibit a reasonable degree of consistency. The difference between the achievement posttest mean score of the male and female students is 2.12 and in favour of the male students.

In the same vein, the male students gained 16.33 in achievement scores, while the female students gained 13.82. This implies that, on average, male students experienced a greater increase in achievement scores compared to female students. Specifically, the difference in the mean gain between the two groups indicates that male students, on average, improved their achievement scores by 2.51 more units than their female counterparts throughout the study. This suggests a disparity in the rate of achievement between male and female students, with males exhibiting a larger improvement in achievement scores when taught geometry using a laboratory instruction strategy.

Research question three

what is the interaction effect of the method of teaching and gender on students' achievement in geometry?

Fig 1 is a profile plot of the adjusted means for the achievement test, split for male and female students and method of teaching (laboratory-based method and conventional lecture method). The plot shows that the male and female students' achievement scores intersect, which is indicative of an interactive effect. The lowest achievement scores of the males and females in geometry occur in the conventional lecture method. On the other hand, the highest score was recorded for male students in the laboratory-based method. This suggests that males and females appear to respond differently to the method of teaching and that in designing the laboratory-based method, consideration should be made for gender.

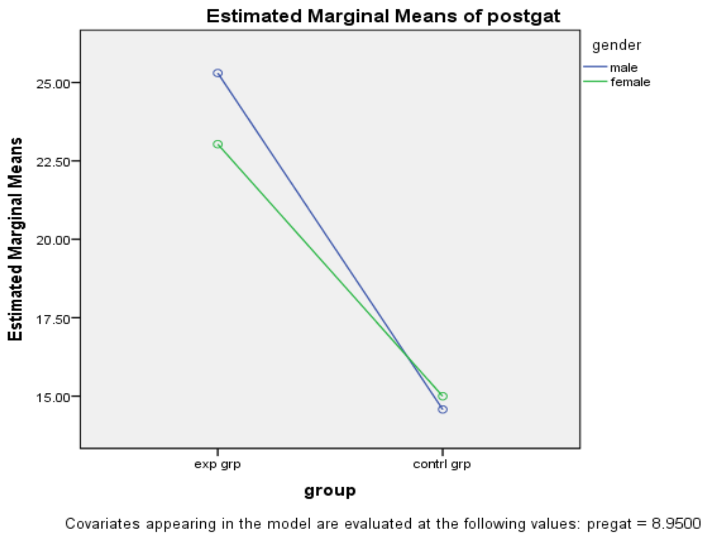

Figure 1. Profile plot of interaction for the method of teaching and gender

Hypothesis one

The laboratory-based method has no significant effect on Upper Basic II students' achievement in geometry.

Table 3. One-way ANCOVA of laboratory-based method on Students' Achievement in Geometry

Sources of Variation	Sum of squares	df	Mean square	F	Sig.	Partial Eta squared
Corrected Model	3775.23[a]	2	1887.615	111.89	0.00	0.59
Intercept	4853.74	1	4853.74	287.72	0.00	0.65
Pre-test	243.02	1	243.02	14.41	0.00	0.08
Method	3345.33	1	3345.33	198.30	0.00	0.56
Error	2648.55	157	16.87			
Total	71468.00	160				
Corrected Total	6423.78	159				

a. R Squared = .588 (Adjusted R Squared = .582)

Table 3 is a one-way between-groups analysis of covariance to evaluate the mean achievement scores of students taught geometry using laboratory-based method. The analysis reveals compelling evidence regarding the effect of the laboratory-based method on Upper Basic II students' achievement in geometry. Firstly, after adjusting for pre-test scores, a significant difference is observed between the two groups in terms of students' post-test scores, as evidenced by the obtained F-statistic of 198.30 with a p-value of 0.00, indicating statistical significance. Moreover, the substantial effect size, represented by a partial eta-squared value of 0.56, suggests that a considerable portion (56%) of the variance in achievement scores can be attributed to the laboratory-based method employed. Additionally, it is noted that although there is a statistically significant difference between pretest and post-test scores, the observed relationship between these scores is relatively weak, as indicated by a partial eta-squared value of 0.08. Considering these findings, the hypothesis suggesting that the laboratory-based method has no significant effect on students' achievement in geometry is hereby rejected. Instead, the results indicate a significant positive effect of the laboratory-based method on students' achievement in geometry.

Hypothesis two

There is no significant difference between male and female students' achievement in geometry when the laboratory-based method is used.

Table 4. One-way ANCOVA of gender differences in Students' Achievement in algebra

Sources of Variation	Sum of Squares	df	Mean square	F	Sig.	Partial Eta squared
Corrected Model	205.18[a]	2	102.59	4.67	0.01	0.09
Intercept	5949.20	1	5949.20	270.87	0.00	0.75
Pre-test	102.30	1	102.30	4.66	0.03	0.05
Gender	113.91	1	113.91	5.19	0.03	0.05
Error	1976.71	90	21.96			
Total	56424.00	93				
Corrected Total	2181.89	92				

a. R Squared = .094 (Adjusted R Squared = .074)

Results from Table 4 show a one-way between-groups analysis of covariance to compare the mean achievement scores of male and female students taught geometry using laboratory-based method. The statistical analysis indicates that after controlling for pre-test scores, there is a significant difference between the achievement scores of male and female students. This is evidenced by the obtained F-statistic of 5.19, with an associated significance level (p-value) of 0.03, which is less than the conventional threshold of 0.05. However, it is crucial to interpret the practical significance of this statistical finding. The effect size, as measured by partial eta squared, provides insight into the magnitude of the difference observed between male and female students' achievement scores. In this case, the partial eta-squared value of 0.05 suggests that only 5% of the variance in achievement scores can be attributed to gender differences among students. Therefore, while the statistical test indicates a significant difference between male and female students' achievement scores, the effect size reveals that this difference accounts for a relatively small proportion of the overall variance in achievement scores.

The analysis further reveals that there is a weak relationship between the pretest and post-test scores in both male and female students' achievement scores, as indicated by a partial eta-squared value of 0.05. This suggests that the pretest scores do not influence the post-test scores for both genders. As a result, the hypothesis positing no significant difference between achievement scores of male and female students taught geometry using the laboratory-based method at the Upper Basic School level in the Jalingo metropolis is rejected.

Hypothesis three

There is no significant interaction effect of the method of teaching and gender on Upper Basic II students' achievement in geometry.

Table 5 shows the results of a 2 x 2 x 1 factorial analysis, examining the interactive effect of the method of teaching (laboratory-based and conventional lecture methods) and gender (male and female) on students' achievement in geometry. The statistical analysis reveals a significant interaction effect between the method of teaching and gender on students' achievement scores in geometry, as indicated by the obtained F-statistic of 4.26 with a significance level (p-value) of 0.04, which is less than the predetermined threshold of 0.05. This suggests that the combination of teaching method and gender influences students' achievement scores differently than what would be expected from the individual effects of each factor alone. Furthermore, the effect size associated with this interaction effect indicates that approximately 3% of the variance in achievement mean scores can be attributed to the combination of teaching method and gender. This suggests that, while statistically significant, the practical significance or magnitude of the interaction effect may be relatively modest, with other factors likely contributing to the variability in achievement scores among students. Therefore, the null hypothesis of no significant interaction effect of method of teaching and gender on students' achievement scores in geometry in the Jalingo metropolis is rejected.

Table 5. One-way ANCOVA of the method of teaching and gender on Students' Achievement in Geometry

Sources of Variation	Sum of Squares	df	Mean square	F	Sig.	Partial Eta squared
Corrected Model	3896.37[a]	4	974.09	59.74	0.00	0.61
Intercept	4819.51	1	4819.51	295.57	0.00	0.66
Pre-test	257.57	1	257.57	15.80	0.00	0.09
Method	3352.90	1	3352.90	205.63	0.00	0.57
Gender	32.63	1	32.63	2.00	0.16	0.01
Method*Gender	69.40	1	69.40	4.26	0.04	0.03
Error	2527.40	155	16.31			
Total	71468.00	160				
Corrected Total	6423.78	159				

a. R Squared = .607 (Adjusted R Squared = .596)

5. DISCUSSION OF FINDINGS

Descriptive and inferential statistics were utilized to evaluate the effect of the laboratory-based method on geometry achievement. The method of teaching (specifically, the laboratory-based method) was designated as the independent variable, with gender as a moderator variable. The dependent variable was the achievement score in geometry. Data on this variable were collected both before and after the experiment. Pre-treatment data, labelled as the pretest, served as a covariate to adjust for initial differences between groups. Post-treatment data (post-test) were analysed to assess the intervention's effect. Preliminary checks ensured that assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliability of covariate measurements were not violated, thereby confirming the robustness and validity of the statistical analyses.

This study revealed that the laboratory-based method significantly enhanced students' geometry achievement. Implementing the laboratory-based method led to improved learning outcomes, aligning with previous findings by Ngala (2019), Anakpua et al. (2020), David et al. (2022), Bindu and Ramakrishna (2023), and Jepkosgei (2023), all of whom reported that laboratory-based teaching improves comprehension and achievement in mathematics. The results indicate that the laboratory-based method's impact on achievement was both statistically significant and practically meaningful, with 56% of the variance in scores attributable to this instructional approach. This substantial effect size underscores the efficacy of the laboratory-based method as an impactful educational strategy, promoting student engagement and supporting better retention of geometric concepts.

The effectiveness of laboratory-based methods can be attributed to their alignment with active learning principles, which emphasize student participation, experimentation, and real-world application of concepts. Geometry, a subject often challenging due to its abstract nature, becomes more approachable when students interact with physical representations, engage in group problem-solving, and apply concepts in hands-on settings. This experiential approach likely contributed to students' increased comprehension, as they were able to see the relevance of geometric principles in everyday contexts, fostering deeper cognitive connections.

Additionally, the laboratory-based approach aligns with constructivist theories, where students actively construct knowledge through direct interaction with materials and guided exploration. This process facilitates a stronger grasp of complex concepts, as students learn through doing, experimenting, and reflecting on their learning. The opportunity to explore geometry through physical and visual means likely enhanced students' spatial reasoning and problem-solving skills, which are critical components of mathematics education. The positive effects observed in this study suggest that laboratory-based instruction can provide a dynamic and inclusive learning environment, catering to diverse learning styles and preferences, and enhancing the overall learning experience in mathematics.

Furthermore, the observed improvement in student achievement supports the idea that laboratory-based methods not only enhance immediate understanding but also promote longer-term retention of learned concepts. By engaging multiple senses and reinforcing learning through practical application, students are more likely to internalize key ideas, making this approach valuable for sustained educational outcomes. The findings from this study advocate for wider implementation of laboratory-based methods in mathematics education, especially in topics such as geometry, where interactive and visual learning experiences can significantly enhance comprehension and academic performance.

Analysis of Gender Differences

An interesting finding in this study was the discrepancy in achievement scores between male and female students taught geometry through the laboratory-based method, with male students demonstrating greater improvements. This difference may be attributed to sociocultural factors influencing how male and female students engage with interactive learning activities. In many contexts, including Nigeria, male students may have greater exposure to hands-on activities and resources outside school, such as technical or manual tasks that can enhance spatial reasoning skills. Additionally, male students may respond differently to competitive, group-based learning environments, potentially finding these activities more engaging and motivating. Research by Busola (2011) and Asuquo and Onasanya (2006) supports the idea that gender can influence performance in interactive learning settings, though other studies, such as those by Oludipe (2012) and Wushishi et al. (2016), suggest that gender differences in achievement may vary depending on context.

In contrast to these studies, the findings of this study align with those of Busola (2011), who also reported that male students outperformed their female counterparts in subjects involving spatial reasoning and hands-on engagement. Busola (2011) argued that male students' greater familiarity with spatial tasks outside the classroom context may contribute to their advantage in such activities. Similarly, Asuquo and Onasanya (2006) highlighted how gendered societal roles and early exposure to specific types of tasks may lead to differences in performance in interactive and laboratory-based learning environments.

On the other hand, the findings in this study stand in contrast to those of Oludipe (2012), who found no significant difference in the achievement scores of male and female students in geometry, suggesting that when laboratory-based methods are employed, both genders can benefit equally from the hands-on approach. This highlights that while sociocultural factors may play a role, instructional methods themselves can bridge the gender gap, depending on how effectively they are implemented.

Moreover, Wushishi et al. (2016) found that gender differences in achievement were often context-dependent, with some contexts showing no significant differences in performance. This supports the idea that the laboratory-based method, if adapted appropriately to the specific needs of the students, might diminish the gender disparity observed in other traditional instructional settings. Therefore, while the male students in this study showed greater improvements, the context of the learning environment, coupled with the instructional approach, remains a critical factor in determining how gender influences academic achievement in mathematics education.

Other Contributing Factors

While the laboratory-based method significantly impacted achievement, other factors could also contribute to variations in student performance. External influences, such as socioeconomic background, school resources, and prior exposure to geometry, could play a role. For instance, students from schools with better resources, such as geometry tools and visual aids, may have an advantage in achieving higher scores. Additionally, socio-economic factors, such as parental support or access to additional learning materials at home, can affect student outcomes. Understanding these influences can help educators and policymakers tailor interventions to address diverse needs and improve educational equity.

Further studies by Alhassan and Omidiora (2013) and Adeyemo (2008) have corroborated the idea that socio-economic status plays a crucial role in student performance, particularly in subjects requiring practical engagement like geometry. Their research suggests that students from higher socio-economic backgrounds often have access to supplementary learning tools, such as textbooks, computers, and even private tutoring, which can enhance their understanding of complex concepts. This, in turn, leads to improved academic performance, as these students are better equipped to navigate the challenges of laboratory-based and hands-on learning.

In contrast, students from lower socio-economic backgrounds might face constraints that hinder their engagement with interactive learning methods. These challenges include limited access to educational materials, insufficient parental support, and less exposure to academic resources outside of school. According to Fuchs and Woessmann (2007), these factors create an uneven playing field, where students from disadvantaged backgrounds are at a distinct disadvantage, even if the instructional method is effective.

Additionally, prior exposure to geometry can also play a role in students' success in laboratory-based learning. Research by Ogundele (2015) found that students with prior experience in geometry, either through exposure in earlier grades or through family members with a strong understanding of mathematics, tend to perform better in geometry-related tasks. This prior knowledge can provide a foundation that allows students to better engage with the laboratory-based approach, maximizing the benefits of interactive learning.

Thus, while the laboratory-based method is an effective instructional strategy, it is essential to recognize that achievement outcomes may be influenced by a combination of these external factors. Addressing these issues requires a multifaceted approach that ensures all students have equal access to the resources and support they need to succeed. This understanding can help educators and policymakers design interventions that not only focus on instructional methods but also consider the broader socio-economic and contextual factors that affect student achievement.

Practical Implications of Findings

The findings suggest that laboratory-based instructional methods have substantial potential to improve math outcomes by actively engaging students and making abstract concepts more accessible. Such approaches can be particularly valuable in educational settings where students benefit from hands-on learning, as they enhance classroom engagement and facilitate a deeper understanding of complex topics like geometry. This approach could therefore serve as an effective model for similar educational contexts aiming to enhance STEM education outcomes.

In support of this, studies by Akinsola and Tella (2006) have emphasized the benefits of interactive, hands-on learning in mathematics classrooms, noting that students often demonstrate improved understanding and retention when they can physically manipulate objects or interact with visual aids. The laboratory-based method provides an opportunity for students to explore mathematical concepts tangibly, thus bridging the gap between abstract theories and real-world applications. For instance, when students engage with geometric shapes through hands-on activities, they can better grasp concepts like area, volume, and spatial relationships, which are often challenging to understand through traditional lecture-based instruction alone.

Additionally, the laboratory-based method can foster greater student collaboration and communication. According to research by Johnson and Johnson (2009), collaborative learning in laboratory settings promotes social interaction, critical thinking, and peer learning. In group-based laboratory activities, students are encouraged to share ideas, solve problems together, and support one another in understanding complex mathematical concepts. This social aspect not only helps reinforce individual learning but also builds important teamwork and communication skills that are essential in both academic and professional settings.

Moreover, laboratory-based learning can also serve as a tool for increasing student motivation, particularly in STEM subjects. According to the Self-Determination Theory (Deci & Ryan, 1985), when students are given autonomy and the opportunity to engage in activities that are meaningful and interesting to them, they are more likely to develop intrinsic motivation and sustain their engagement with the subject matter. In this context, laboratory-based methods can provide a more stimulating and enjoyable learning experience, increasing students' intrinsic motivation to explore mathematical concepts further and persist in the subject.

While the positive impact of laboratory-based methods is clear, the effectiveness of this approach depends on the quality of the implementation. Research by PISA (OECD, 2017) highlights that the successful integration of hands-on learning requires proper training for teachers, adequate resources, and a supportive classroom environment. Teachers need to be well-versed in facilitating interactive learning and in making the most of laboratory materials to ensure that the students' engagement translates into meaningful learning. In settings where resources are limited, however, the challenges of implementing such methods can be significant, making it important for policymakers to invest in both teacher professional development and the provision of adequate learning materials.

Ultimately, laboratory-based instructional methods offer a promising avenue for enhancing STEM education outcomes, especially in contexts where students can benefit from active engagement and real-world application of mathematical principles. By promoting student-centred learning, improving understanding of abstract concepts, fostering collaboration, and increasing motivation, this approach aligns with broader educational goals of improving student achievement and preparing students for the challenges of the modern world.

Limitations of the study

This study has certain limitations. The focus on a single city, Jalingo, and the relatively small sample size may limit the generalizability of these findings, as the educational and socio-cultural factors influencing student performance in Jalingo may differ from those in other regions. Additionally, the study’s reliance on short-term achievement measures may not fully capture the long-term effects of laboratory-based learning on students’ comprehension and retention of geometric concepts. Future research with a larger, more diverse sample across different cities and socio-economic contexts would help validate these results and provide a more comprehensive understanding of how laboratory-based methods impact mathematics learning in various educational settings.

Furthermore, this study did not account for individual differences in learning styles and prior exposure to geometry, which could influence how effectively students engage with hands-on learning methods. Future studies might benefit from examining how these individual differences interact with instructional methods, as well as investigating the role of teacher expertise in implementing laboratory-based strategies. By addressing these factors, subsequent research could yield deeper insights into the adaptability and scalability of laboratory-based instruction in diverse educational contexts.

6. CONCLUSION AND RECOMMENDATIONS

In conclusion, the findings from this study underscore the effectiveness of the laboratory-based method in enhancing learning outcomes in geometry. By providing hands-on, interactive learning experiences, this approach fosters a deeper understanding of mathematical concepts and supports improved student achievement. The success observed in this study suggests that laboratory-based methods hold significant potential for broader application in mathematics education, especially in settings where active learning can bridge gaps in conceptual comprehension.

To maximize the benefits of this approach, it is recommended that schools and mathematics teachers consider integrating laboratory-based methods more extensively into the mathematics curriculum. This would likely require increased investment in resources, such as geometry tools and manipulatives, as well as targeted training for teachers to develop the necessary skills for implementing interactive, student-centred activities. Schools may initially face challenges related to resource constraints, teacher preparedness, and the restructuring of lesson plans to accommodate laboratory activities. To address these challenges, phased implementation or pilot programs could be introduced, allowing schools to gradually adopt the method while building capacity and gathering data on its effectiveness.

Future research should extend the scope of this study by exploring the impact of laboratory-based methods on other mathematics topics, such as algebra or trigonometry, to determine if similar improvements can be achieved across different areas of mathematics. Additionally, applying this instructional method in varied Nigerian regions would provide insights into its adaptability and effectiveness across diverse educational and socio-cultural contexts. Such research could help identify the specific components of the laboratory-based approach that yield the most substantial gains in student learning, ultimately refining the method and optimizing its impact. By continuously assessing and refining laboratory-based methods, educators and policymakers can work towards creating a more engaging, equitable, and effective mathematics education system that better meets the needs of students across Nigeria.

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