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Effects of Virtual and Physical Mathematics Laboratory Strategies on Senior Secondary School Students' Academic Achievement in Geometry in Oyo South Senatorial District, Nigeria

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Abstract

Poor performance in Mathematics is one area of concern to all stakeholders in Nigeria. Despite its central place in the secondary school Mathematics curriculum and its importance to science, technology, engineering and Mathematics (STEM) pathways, many students still struggle with geometric concepts. This informed this study on the Effect of Virtual and Physical Mathematics Laboratory Strategies on Senior School Students' Achievement in Geometry in Oyo South Senatorial District. The study adopted a pretest–posttest Quasi-experimental design involving non randomized and non-equivalent intact groups of 387 SS II students from three co-educational public secondary schools from a population of 17,980. The three intact classes were assigned to Virtual Mathematics Laboratory using GeoGebra (VML, n = 129), Physical Mathematics Laboratory with concrete manipulatives (PML, n = 129), and Conventional Teaching Strategy (CTS, n = 129). A validated and reliable 30-item Geometry Achievement Test (KR-20 =0.87) was used for data collection. Data were analysed with Analysis of Covariance (ANCOVA), using pretest scores as covariate. Results showed a clear main effect of instructional strategy, $F(2, 380) = 99.238$, $p < 0.001$. Adjusted post-test means were 42.32 (VML), 37.92 (PML) and 30.73 (CTS). All pairwise differences were significant, giving the order VML > PML > CTS. The findings concluded that laboratory strategies, especially the virtual laboratory with GeoGebra, improve geometry achievement more than conventional teaching. The study recommended integrating these strategies into secondary Mathematics classrooms, backed by teacher preparation and adequate resources.

Keywords: *Geometry Achievement, GeoGebra, Physical Mathematics Laboratory, Secondary education, Virtual Mathematics Laboratory*

Introduction

Mathematics has long been recognized as the foundation upon which the edifice of modern science, technology, and socio-economic development is built. From the simplest calculation of everyday transactions to the most complex modelling of climate change and artificial intelligence, Mathematics remains the universal language through which human beings make sense of the world. Its centrality in education systems across the globe reflects not only its functional utility but also its power to train the human mind in logical reasoning, systematic problem-solving, and analytical thinking. In Nigeria, the importance of Mathematics is formally acknowledged through its status as a compulsory subject at both the junior and senior secondary school levels. The Nigerian Educational Research and Development Council (NERDC, 2013), which is responsible for curriculum development in the country, has consistently placed Mathematics at the heart of the secondary school curriculum, recognizing that no meaningful national development can occur without a citizenry that is mathematically literate.

Despite its acknowledged importance, however, the academic achievement of Nigerian students in Mathematics has remained a matter of deep national concern. Year after year, external examination results from the West African Examinations Council (WAEC) reveal alarming rates of failure and poor performance in the subject (WAEC, 2021; 2022; 2023; 2024). A minimum credit pass in Mathematics (grade C6 or better) is a prerequisite for admission into virtually all degrees, diplomas and certificate programmes in Nigerian universities, polytechnics, and colleges of education

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respectively. Irrespective of this importance, a significant proportion of candidates consistently fail to attain this minimum requirement, thereby putting them at disadvantages to obtain higher education admissions opportunities to science related courses and limiting their prospects in a technology-driven labour market. This persistent underperformance represents a major barrier to any society's aspirations of becoming a part of a leading global knowledge economy (Danişman, 2026).

Within the broad domain of school Mathematics, geometry stands out as one of the most persistently challenging topics for Nigerian secondary school students. Geometry is the branch of Mathematics that deals with the shapes, sizes, relative positions, and properties of figures and spaces. It encompasses the study of points, lines, angles, surfaces, and solids, providing the mathematical foundation for disciplines as varied as architecture, engineering, land surveying, computer graphics, robotics, and visual arts (Sam-Kayode, 2025). A student with a solid grounding in geometry is well equipped not only for further academic studies in the natural and applied sciences but also for the kind of spatial and logical reasoning that is increasingly valued in the modern workplace.

Geometry is frequently identified in examination reports as one of the weakest areas of student performance in Nigerian secondary school Mathematics. The WAEC Chief Examiner's Reports across multiple years have highlighted the inability of candidates to correctly apply geometric theorems, perform geometric constructions accurately, solve coordinate geometry problems, and interpret geometric figures in real-life contexts. These weaknesses suggest a fundamental gap between the way geometry is taught in Nigerian classrooms and the way it is understood and applied by students. Rather than developing a conceptual and experiential understanding of geometric ideas, most students are taught to memorize theorems, formulas, and procedures, which they then apply mechanically without genuine comprehension (WAEC, 2021; 2022; 2023; 2024).

The root of this problem lies largely in the dominance of the conventional teaching strategy in Nigerian secondary school Mathematics classrooms. The conventional teaching strategy also known as the traditional or teacher-centered approach is an instructional method in which the teacher acts as the sole authority and transmitter of knowledge. The teacher explains concepts verbally, writes proofs and formulas on the chalkboard, works through examples, and then assigns exercises from prescribed textbooks. Students are expected to listen, copy notes, memorize rules, and reproduce what they have been taught under examination conditions. There is little or no provision for exploration, questioning, or hands-on discovery. In this approach, geometric concepts which are inherently visual and spatial in nature are reduced to abstract symbols and rules that students are expected to commit to memory without genuine understanding. This fundamental mismatch between the nature of geometry and the prevailing method of its instruction is a primary reason why so many students find the subject confusing, disengaging, and ultimately beyond their grasp.

In response to the inadequacies of conventional teaching, Mathematics educators and researchers have strongly advocated for the adoption of more active learner-centered strategies. One of the most widely recommended alternatives is the Mathematics laboratory approach, which provides a purposefully designed environment in which students engage in hands-on exploration and discovery of mathematical concepts through guided experimentation, measurement, observation, and reflection (Almubarak, Maat, & Mahmud, 2025). This shift from passive reception to active construction of knowledge is consistent with the principles of constructivist learning theory, which holds that learners build meaningful understanding through direct engagement with their learning environment. Within this framework, two prominent strategies have emerged and attracted significant research attention, the physical Mathematics laboratory and the virtual Mathematics laboratory.

The advocacy for laboratory approaches is not merely a matter of pedagogical fashion. It rests on a substantial body of cognitive and educational research demonstrating that active, multi-representational learning produces deeper and more durable understanding than passive reception. In geometry specifically, the research base includes controlled experiments, classroom studies, meta-analyses of manipulative and dynamic-geometry interventions, and theoretical analyses grounded in constructivist, constructionist and sociocultural (Okigbo & Okeke, 2021; Zhang et al., 2025).

The persistence of weak geometry performance across successive cohorts of Nigerian secondary school candidates points to systemic rather than idiosyncratic causes. If the problem were confined to a particular school, teacher or examination year, variation in outcomes would be expected. The consistency of the pattern across years, states and examination bodies indicated that the dominant instructional approaches are systematically failing to develop the geometric understanding that the curriculum and the examinations require. Laboratory-based strategies offer a theoretically grounded alternative that directly addresses the visual, spatial and constructive character of geometric knowledge (Almubarak, Maat, & Mahmud, 2025). The present study situates itself within this research tradition while addressing the specific comparative and contextual questions that remain unanswered for Oyo South Senatorial District. Here in this study, two laboratory-based teaching strategies are considered for the teaching of geometry at the senior secondary school level. These are; physical Mathematics laboratory (PML) and virtual Mathematics laboratory (VML).

Physical Mathematics laboratory (PML) involves the use of concrete, tangible materials such as rulers, compasses, protractors, set squares, graph boards, three-dimensional geometric models or geoboards. In a physical laboratory session on geometry, students might use compasses and straight edges to construct angle bisectors and perpendicular

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lines, manipulate geoboards to explore properties of polygons, or handle three-dimensional models to investigate the surface areas and volumes of solids. This approach is firmly grounded in Jerome Bruner's enactive mode of representation and Jean Piaget's constructivist theory, both of which hold that learners build knowledge more effectively when they are actively involved in tangible, real-world experiences (Piaget, 1977).

Virtual Mathematics laboratory (VML) on the other hand harnesses the power of digital technology to create a dynamic, interactive, and visual learning environment for Mathematics. The VML uses computer software and internet-based platforms such as GeoGebra, Desmos, Cabri Geometry, and the Geometer's Sketchpad to simulate mathematical experiments and activities (Almubarak, Maat, & Mahmud, 2025; Sam-Kayode & Raheem, 2026). These tools give students the ability to construct geometric figures with precision, drag and manipulate them in real time, measure angles and lengths dynamically, and test geometric conjectures by observing what remains invariant as figures are altered. The theoretical underpinnings draw from Vygotsky's social constructivism and Piaget's constructionism, both of which emphasize learning through active creation using meaningful, intellectually stimulating tools (Piaget, 1977; Vygosky, 1978).

Beyond their individual theoretical justifications, both the PML and VML strategies share a common commitment to making Mathematics more accessible, engaging, and meaningful for learners. They both challenge the passive, receptive model of learning that dominates conventional instruction and replace it with a learner-centered, process-oriented approach in which students are active constructors of mathematical knowledge. Research has consistently showed that students who engage in active, exploratory learning activities develop not only stronger conceptual understanding but also higher levels of intrinsic motivation, better retention of mathematical knowledge over time, and more positive attitudes towards Mathematics as a subject and as a discipline. These outcomes are particularly significant where negative attitudes towards Mathematics are widespread and deeply entrenched among secondary school students (Danişman, 2026).

The global research literature on the comparative effectiveness of virtual and physical laboratory strategies in Mathematics and science education is both rich and complex. Findings have been mixed and context-dependent. Some studies report that virtual laboratory environments outperform physical ones in terms of student engagement and conceptual understanding, while others find that physical, concrete manipulative experiences produce deeper and more durable learning outcomes. A research outcome suggested that the most effective outcomes are achieved when both strategies are combined or used complementarily (Almubarak, Maat, & Mahmud, 2025; Sam-Kayode & Raheem, 2026). Importantly, most existing studies have been conducted in developed-country contexts, and there is a clear need for research that speaks directly to the realities of African secondary school settings.

A careful reading of the comparative literature reveals that the relative advantage of virtual versus physical laboratories is often moderated by the nature of the geometric content, the duration of the intervention, the quality of teacher facilitation, and the prior knowledge and digital experience of the learners. Some studies find virtual environments superior for topics involving continuous variation and invariance; others find physical materials superior for topics involving measurement, construction and three-dimensional spatial relations. Still, others find equivalent outcomes when both approaches are implemented with high fidelity. These nuanced findings underscore the importance of context-specific research rather than universal prescriptions (Atit et al., 2022**)**.

A critical factor that shapes the effectiveness of any instructional strategy is the quality and preparedness of the teacher who implements it. In Nigeria, many Mathematics teachers at the secondary school level received their professional training at a time when laboratory-based and technology-enhanced pedagogies were not systematically taught or practiced. As a consequence, even when schools possess some laboratory resources or access to computers, many teachers lack the confidence, the technical competence, and the pedagogical knowledge to deploy these tools effectively in their classrooms. Teacher capacity building is therefore a necessary condition for the successful implementation of either the virtual or the physical

Teacher capacity building is therefore not an optional adjunct to laboratory-based reform but a necessary condition for its success. Studies that have included structured professional development have generally reported larger achievement gains than those that have simply provided materials or software without accompanying pedagogical support. The present study's incorporation of a one-week teacher orientation programme, covering both the technical and the pedagogical dimensions of VML and PML implementation, is designed to maximise the fidelity of the interventions and to isolate, as far as possible, the effects of the strategies themselves from the effects of uneven teacher preparation.

The present study incorporated a structured teacher orientation programme as part of its design, ensuring that the participating teachers were adequately trained to deliver the laboratory-based interventions with fidelity before the study commenced. The role of theoretical frameworks in guiding the design and interpretation of this study deserves explicit recognition. Three theoretical perspectives are particularly relevant. First, Jean Piaget's theory of cognitive development emphasizes that learners in the formal operational stage, which includes most senior secondary school students, are capable of abstract reasoning but benefit significantly from concrete or semi-concrete experiences that provide a bridge between the physical and the abstract. Geometry, with its blend of visual intuition and formal proof, is particularly well suited to instruction that begins with concrete or visual exploration before progressing to abstract generalization (Piaget, 1970).

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Taking a lift from Jerome Bruner's theory of instruction, three modes of representation were identified on how learners come to understand new concepts: the enactive mode (learning by doing), the iconic mode (learning through images and diagrams), and the symbolic mode (learning through language and symbols). The physical Mathematics laboratory primarily engages the enactive and iconic modes, while the virtual Mathematics laboratory engages the iconic and, to a lesser extent, the symbolic modes. Both approaches therefore offer a richer and more developmentally appropriate pathway to geometric understanding than the conventional method, which operates almost exclusively at the symbolic level **(**Bruner, 1966).

Third, Lev Vygotsky's sociocultural theory draws attention to the importance of social interaction and the use of cultural tools in learning (Vygosky, 1978). Both the physical and virtual laboratory strategies create opportunities for collaborative learning, peer discussion, and the use of tools whether physical or digital as mediating devices that extend the learner's cognitive capabilities. In this sense, laboratory-based instruction is not merely a practical supplement to conventional teaching; it is a fundamentally different epistemological approach to mathematical knowledge, one that aligns more closely with how mathematical thinking actually develops in human beings (Zhang et al. (2025).

Statement of the Problem

Despite repeated curriculum reviews and the acknowledged importance of geometry, Nigerian senior secondary students continue to underperform in the topic. Conventional teaching methods that emphasise rote learning appear poorly matched to the visual and spatial character of geometry. Although laboratory strategies have been recommended, few local studies have compared the effects of virtual and physical Mathematics laboratories on achievement, or examined whether gender moderates those effects. Without such evidence, teachers and policymakers lack clear guidance on which approaches are most worth investing in. This study investigated the effects of virtual and physical mathematics laboratory strategies on senior secondary school students' academic achievement in geometry in Oyo South Senatorial District, Nigeria. Specifically, it sought to determine the effect of instructional strategy (VML, PML and CTM) on students' achievement in geometry.

Hypotheses

The following null hypothesis was tested at the 0.05 level of significance:

$H_{o}1$: There is no significant effect of instructional strategy on senior secondary school students' academic achievement in geometry.

Methodology

A pretest–posttest, non-equivalent control group quasi-experimental design for this study. The population consisted of all the 17,980 SS2 students in public co-educational secondary schools in Oyo South Senatorial District. Through a multistage process, three Local Government Areas (LGA) were randomly selected, and one co-educational public senior secondary school was chosen from each LGA. Three intact classes were randomly selected from the three selected schools to further establish fairness in sample selections. Pretest scores served as covariate to adjust for any initial differences among the groups. The intact SS2 Mathematics classes in the three schools were assigned to the three treatment conditions, producing a total sample of 387 students. The research instrument used for data collection was Geometry Achievement Test (GAT), a 30-item multiple-choice instrument covering triangle properties, circle theorems, quadrilaterals and polygons. The GAT was used for both pretest and posttest, which items were aligned with the senior secondary Mathematics curriculum. The test was validated by experts in Mathematics Education and Measurement and Evaluation. A pilot study with a comparable group of SS2 students yielded a KR-20 reliability coefficient of 0.87, indicating good internal consistency. Participating Mathematics teachers received a one-week orientation on the respective strategies. This covered both the technical use of GeoGebra or concrete materials and the pedagogical principles of laboratory-based teaching. After the orientation, the GAT was administered as pretest. The intervention lasted eigth weeks. Students in the VML group used GeoGebra to construct, manipulate and measure geometric figures. Those in the PML group worked with geoboards, compasses, protractors and physical models. The CTM group received conventional lecture-based instruction with textbook exercises. The same GAT was then administered as posttest under similar conditions. Descriptive statistics and two-factor Analysis of Covariance (ANCOVA) with pretest as covariate were used. Significance was set at $\alpha = 0.05$. Where a significant main effect of strategy emerged, pairwise comparisons of adjusted post-test means were conducted.

Results

Table 1 shows the mean gains from pretest to posttest for the three groups. Students in the Virtual Mathematics Laboratory gained 19.44 points on average, those in the Physical Mathematics Laboratory gained 14.84 points, and those taught by the Conventional Teaching Method gained only 7.61 points. These raw gains already indicate that both laboratory approaches produced larger improvements than conventional teaching, with the virtual laboratory showing the strongest growth.

Table 1: Mean Gains in Geometry Achievement Test by Instructional Group

Instructional Group	N	Mean Gain	Adjusted Post-test Mean
Virtual Mathematics Laboratory (VML)	127	19.44	42.32
Physical Mathematics Laboratory	129	14.84	37.92

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(PML)			
Conventional Teaching Method (CTM)	131`	7.61	30.73

Source: Researcher's Field work, 2026

Note: Adjusted post-test means were obtained after controlling for pretest scores through ANCOVA.

Test of Hypothesis

Hypothesis One ($H_{o}1$): There is no significant effect of instructional strategy on senior secondary school students' academic achievement in geometry.

Table 2: Analysis of Covariance Report on the Effect of Instructional Strategies on Students Academic Achievement in Geometry

Source	Type II SS	df	MS	F	p	Partial η^2
Pre-test (covariate)	6544.55	1	6544.55	147.516	< 0.001	0.280
Treatment	8805.39	2	4402.70	99.238	< .001	0.343
Gender	84.82	1	84.82	1.912	0.168	0.005
Treatment × Gender	17.20	2	8.60	0.194	0.824	0.001
Error	16858.70	380	44.37	—	—	—
Corrected total	31706.98	386	—	—	—	—

Source: Researcher's Field work, 2026

From the ANCOVA report in table 2, it was revealed that there was a significant effect of instructional strategies on students' academic achievement in geometry, $F_{(2,\ 380)} = 99.238$, $p < 0.001$. This indicates that the type of teaching strategy used made a substantial difference to students' post-test performance after accounting for their initial scores. Hypothesis $H_{o}1$was therefore rejected. Because the main effect of strategy was significant, pairwise comparisons of the adjusted post-test means were examined. All three differences reached statistical significance: VML outperformed PML, VML outperformed CTM, and PML outperformed CTM. The consistent order of effectiveness was therefore VML > PML > CTM.

Discussion of Findings

Based on the results from the findings and the analysis caried out on the results, students who learned geometry through the virtual mathematics laboratory achieved the highest scores. This result is consistent with research showing that dynamic geometry environments help learners visualise continuous change, test conjectures and focus on what remains invariant (Atit et al., 2022; Okigbo & Okeke, 2021). With GeoGebra, a student can drag a point and immediately see how an angle or length responds. Such immediate feedback supports the move from informal observation to formal understanding. The finding also aligns with the recent meta-analysis by Zhang et al. (2025), which reported positive effects of GeoGebra-based dynamic visualisation across years of studies.

The physical laboratory also produced better results than conventional teaching strategy. Working with concrete materials appears to give students a firmer experiential base for abstract geometric ideas, a conclusion that echoes the meta-analysis of **(**Almubarak, Maat, & Mahmud, 2025) on the value of manipulatives. Yet the physical approach did not match the gains achieved with the virtual laboratory. One possible explanation is that software allows many rapid trials with almost no measurement error, whereas physical constructions are slower and more prone to small inaccuracies (Sam-Kayode & Raheem, 2026). Dynamic software also makes continuous variation visible in a way that static materials cannot easily replicate.

One design limitation that should be noted is that, each treatment was delivered in a single school. So, school-level differences remain partly entangled with strategy's effects. Although the use of pretest scores as covariate and the random assignment of schools to conditions reduce this concern, future studies that place multiple schools in each condition would strengthen causal claims. The eight-week duration of the intervention was long enough to detect meaningful differences, but longer-term retention and transfer were not assessed.

Conclusion

Laboratory-based strategies, especially the virtual mathematics laboratory using GeoGebra, improved senior secondary students' achievement in geometry more than conventional teaching strategy in teaching Geometry. Physical laboratory activities also produced meaningful gains as it produced better results than conventional teaching strategy on Geometry. The study therefore concluded that, working with concrete materials due to the manipulative experiences by students would give students a firmer experiential base for

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abstract geometric ideas to better achievement in geometrical concepts in Mathematics

Recommendations

In light of the findings, the following recommendations are offered:

Secondary schools Mathematics teachers should integrate virtual and physical laboratory strategies into geometry teaching, giving priority to dynamic geometry software such as GeoGebra where digital resources are available, and ensuring teachers receive adequate preparation in both the technical and pedagogical aspects of these strategies.

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