PROBLEM-BASED LEARNING AND CONCEPTUAL UNDERSTANDING OF GEOMETRY AMONG PUBLIC SECONDARY SCHOOL STUDENTS IN KIAMBU COUNTY, KENYA

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International Academic Journal of Social Sciences and Education (IAJSSE) | ISSN 2518-2412

Received: 29th October 2026

Published: 25th November 2026

Full Length Research

Available Online at: https://iajournals.org/articles/iajsse_v2_i5_116_129.pdf

Citation: Kamau, S. N., O'connor, M. M., Wambasi, A. W. (2026). Problem-based learning and conceptual understanding of geometry among public secondary school students in Kiambu county, Kenya. *International Academic Journal of Social Sciences and Education, 2*(5), 116-129.

ABSTRACT

Problem-Based Learning (PBL) is a learner-centred instructional approach that engages learners in solving authentic problems, promotes collaboration, and develops critical thinking and conceptual understanding. Despite these benefits, learners' achievement in Geometry in Kenyan secondary schools remains relatively low. This study investigated the effectiveness of PBL in enhancing learners' conceptual understanding of Geometry in Public Secondary Schools in Kiambu Sub-County, Kiambu County, Kenya. The study was underpinned on Constructivist Learning Theory and adopted an embedded mixed-methods approach, incorporating a quasi-experimental non-equivalent control group design. The target population comprised 2,140 Form Three learners and mathematics teachers from 15 public secondary schools. Six schools were selected, yielding an accessible population of 547 Form Three learners. Using Yamane's formula at a 95% confidence level, a sample of 231 learners was determined, while 36 mathematics teachers were purposively selected, resulting in a total sample of 267 respondents. Data were gathered utilizing Geometry Achievement Tests, questionnaires, interview guides, and classroom observation checklists. Quantitative data were analysed utilizing descriptive statistics, whereas qualitative data were analysed thematically. Pre-test results indicated no statistically significant variance between the experimental and control groups ($t = 1.201$, $df = 98$, $p = .233$), confirming comparable baseline achievement. However, post-test results demonstrated a statistically significant variance in favour of the PBL group ($t = -7.303$, $df = 98$, $p < .001$). The experimental group improved from a mean score of 2.79 to 13.30, compared with an increase from 3.25 to 3.69 in the control group. The study concludes that PBL significantly enhances conceptual understanding and achievement in Geometry.

Keywords: Problem-Based Learning, Geometry.

INTRODUCTION

Problem-Based Learning (PBL) has achieved global acclaim as a learner-focused pedagogical method aimed at improving critical thinking, problem-solving abilities, and profound conceptual comprehension. Widely adopted in applied subjects such as mathematics and sciences, PBL fosters active learning by offering students with practical challenges that necessitate collaborative and inquiry-based solutions (Hmelo-Silver, 2019). Research in developed countries such as the US and Finland indicates that PBL enhances pupils' ability to apply mathematical concepts in solving complex problems and promotes long-term retention (Barrows, 2019). This method has also been linked to improvements in students' metacognitive skills, as they learn to monitor and regulate their learning processes (Yew & Goh, 2016).

In some African countries such as Kenya, the curriculum has been focused on the procedural knowledge, whereby pupils are taught how to make the calculation rather than understanding geometric concepts behind it (Bal et al., 2021). This deficiency in mental comprehension is often reflected in low performance in geometry in national and regional assessments such as the Southern and Eastern Africa Consortium for Monitoring Educational Quality (Chijioke & Sanni, 2020). Nevertheless, the value of PBL in promoting mathematical critical thinking and understanding, especially in geometry, is gaining traction in sub-Saharan Africa (Mupa & Chinooneka, 2019) where geometry presents difficulty for many students.

Strengthening of Mathematics and Science in Secondary Education (SMASSE) was commissioned by Japanese International Cooperation Agency (JICA) in 1998 to improve the quality of mathematics and science education in Kenyan secondary schools through learner-centred teaching methods like PBL. In this context, Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) is a key partner offering professional development for teachers to use interactive teaching methods with a problem-solving and real-world application approach, thereby improving student conceptual understanding. The initiative has been determined to enhance student involvement and enhance achievement in strands of the learning areas such as Geometry. However, there are a number of problems that still need to be overcome such as, teachers accustomed to a conventional methodology, lack of teaching resources, pressures from standardized testing, etc.

There has been a growing concern in Kiambu Sub-County for the performance of learners in Mathematics in particular Geometry due to drop in their performance. Educators and policymakers in Kiambu Sub-County have been alarmed by the drop in learners' performance in Mathematics in particular Geometry.

Generally, there are significant gaps in effective teaching strategies for Geometry and mathematics, highlighting a need for targeted research on the impact of PBL to enhance conceptual understanding. Specifically, there is limited investigation into the effects of PBL

on Geometry as a distinct subject, the role of student engagement and attitudes, the influence of socioeconomic factors, and the need for longitudinal studies to track the effectiveness of PBL over time. In Kenya, multiple attempts have been undertaken to include technology in mathematics classroom teaching that involves the use of GeoGebra, a dynamic mathematics software that facilitates interactive learning of mathematical concepts. GeoGebra has been implemented with successful results in different schools in Kenya to improve students' understanding of mathematical concepts such as Geometry (Batiibwe 2024). Using GeoGebra allows students to create and observe geometric constructions, which helps them to see and interact with the shapes and make their abstract ideas more tangible and comprehensible. It also provides students with ways to learn about geometry in more interactive and engaging ways; this is well suited to the notions of PBL. The application of GeoGebra in PBL environments is however, not much studied, nor much has been done on the integration of GeoGebra in improving the teaching and learning process of geometry in PBL environment (Mwingirwa & Miheso, 2016). The research could result in better instructional practices that would enhance the students' achievement in geometry and mathematics in Kiambu Sub-County, Kiambu County, Kenya.

Statement of the Problem

Problem-Based Learning (PBL) is acknowledged as a student-centric pedagogical method that fosters active participation, deep comprehension, cooperative learning, and the practical application of information to real-world issues. PBL is also relevant to the teaching and learning of Geometry as it gives opportunities for pupils to explore concepts, reason spatially, to formulate and solve problems, and apply their knowledge of geometry to real world problems. The use and implementation of PBL in Kenyan's secondary schools is still low despite the benefits that PBL brings into the school, especially in the teaching of Geometry.

The lack of teacher-centred teaching in the teaching of Mathematics is one of the possible reasons for these problems. In such strategies, explanations, demonstrations, memorization of formulas and procedures, and the reproduction of worked examples may be emphasized, while opportunities for learners to investigate problems, build mathematical knowledge, engage in problem-solving activities with peers, and apply mathematical knowledge in new contexts are limited. As a result, some children might be able to learn how to carry out procedures without learning the concepts and problem-solving skills that are necessary to apply the geometric principles efficiently.

Although studies conducted in different educational contexts have reported positive effects of PBL on learners' engagement, conceptual comprehending, and problem-solving abilities, there is inadequate empirical evidence on its application to Geometry at the secondary school level in Kenya. Specifically, there is inadequate knowledge regarding the scope to which PBL is currently integrated into Geometry instruction in public secondary schools in Kiambu Sub-County, the influence of PBL on learners' Geometry achievement, and the contextual factors that facilitate or constrain its implementation. The existing evidence

therefore does not adequately explain whether, and under what conditions, PBL can contribute to improved learning outcomes in Geometry within this context.

This knowledge gap creates a need for systematic investigation of the implementation and influence of PBL in the teaching and learning of Geometry in public secondary schools in Kiambu Sub-County. The research will therefore determine the extent to which PBL is integrated into Geometry instruction, examine its influence on learners' academic performance in Geometry. The results are anticipated to furnish empirical evidence to inform Mathematics teaching practices, teacher professional development, school-level support, and educational policy on the effective integration of PBL in Geometry instruction.

Purpose of the Study

The study purpose was to determine how the application of Problem-Based Learning (PBL) influences pupils' learning of Geometry in Kenyan secondary schools. The research aimed to establish whether the integration of PBL into the teaching of Geometry enhances students' conceptual understanding, problem-solving skills, engagement, and academic achievement compared with conventional teacher-centred instructional approaches.

Theoretical Framework

This research was underpinned on Constructivist Learning Theory, as advanced by Jean Piaget (1936) and later expanded by Lev Vygotsky (1978). The theory asserts that learners actively construct knowledge via experiences and interactions with their environment. This perspective aligns well with PBL, an educational approach that emphasizes pupil engagement, collaboration, and real-world problem-solving to promote a deeper comprehension of concepts such as geometry. Central to Constructivist Learning Theory are the contributions of several key theorists whose ideas inform the study's approach. Jean Piaget's Cognitive Development Theory stresses that learners build knowledge by actively exploring their environment, assimilating new information into existing cognitive structures (schemas), and adapting these structures through accommodation. Piaget's stages of cognitive development offer a practical framework for comprehending the manner in which students develop complex mathematical concepts like geometry. Recent research, such as the work by Serpell and Ginsburg (2020), continues to affirm Piaget's relevance in modern education, particularly in exploring how learners grasp abstract mathematical ideas.

REVIEW OF RELATED LITERATURE

Divrik et al. (2020) discussed the issue of teachers' involvement in problem-posing activities and emphasized the role of teachers' perceptions and skills in teaching mathematics. Their results indicate that the knowledge of the teachers about the problem-oriented approaches can have an effect on the implementation in the classroom. Even though the study did not specifically target Geometry in Kenyan public secondary schools, it offers valuable evidence on teacher practices in the implementation of problem-oriented mathematics teaching in secondary schools.

Technology also can aid in the integration of PBL into Geometry. Technology tools can be used to improve PBL experiences, according to Branch (2015). In the area of Geometry, digital tools can help students visualize shapes, manipulate geometric figures, explore relationships, and make conjectures.

Tursynkulova (2023) observes that PBL can promote transfer of learning by offering learners with opportunities to apply knowledge to practical and unfamiliar situations. In Geometry, students might use knowledge of angles, shapes, measurement, transformations, spatial relationships, and geometric reasoning in real-world situations. Wilder (2015) also suggests that PBL can enhance conceptual understanding and memory.

Tong et al. (2021) compared the attitudes of senior high school students in relation to integrated STEM learning by comparing with those of students taught by more conventional methods and concluded that PBL learners had more positive attitudes than conventional learners. Although the study was conducted in Taiwan, its findings provide evidence of the potential benefits of PBL in mathematics-related learning.

Hanefar et al. (2021) similarly reported favorable effects of PBL on critical thinking, collaboration, and classroom participation. However, their study focused on tertiary education rather than secondary school Geometry. Merritt et al. (2017) reviewed applications of PBL in mathematics and science and identified benefits related to engagement and understanding, while Holmes and Hwang (2016) provide evidence supporting problem-oriented approaches in mathematics education.

METHODOLOGY

The study used a non-equivalent control group design, which is a quasi-experimental research approach. The design was deemed suitable as it allowed for comparison between the groups while avoiding the individual allocation of participants as this is not always practical in natural school environments.

Available records indicate that there are 303 secondary schools in Kiambu County with 227 being public and 76 being private. There are 89,065 students total across all schools, with 44,777 of those being male, and 44,288 being female. This research confined itself to concerned public secondary schools which are 231 in number. The majority of students attend these schools and they share an administrative and policy framework. Given logistical and accessibility issues, it was not possible to conduct a study of all schools, but rather a manageable and representative sample of the population was studied.

Stratified sampling technique was applied to ensure satisfactory representation of the various Schools in Public Secondary Schools in Kiambu Sub County namely, boys' schools, girls' schools and mixed schools. These categories were used as the first stratification of the population and then schools were randomly sampled to be representative of each stratum in

the study. Quasi-experimental sampling method was also utilized to select intact classes from the selected schools. In this study, Geometry Achievement Tests (GAT) (Pre-Test and Post-Test), In-Depth Interview, Self-Administered Questionnaires and an Observation Checklist were employed to gather data aligned with the research goal.

PRESENTATION OF FINDINGS, INTERPRETATION, ANALYSIS AND DISCUSSION

Extent of Problem-Based Learning (PBL) integration into Geometry Lessons.

This section presents findings on the extent to which teachers integrate PBL into Geometry lessons in Public Secondary Schools. The results indicate the exetent of teachers' implementation and classroom application of PBL practices, including the extent to which teachers use problem-based tasks, facilitate learner collaboration, encourage inquiry, and support students in constructing mathematical solutions during Geometry lessons.

The results indicated the extent of teachers reported PBL integration efforts (low, moderate, or high). Descriptive results are presented first followed by further analysis of relationships among the variables of relevance. The results are summarized in the tables and figures below. The results are exhibited below.

Table : Level of implementation of PBL in Kiambu Sub-County Public Secondary Schools (Students, N=231).

Level	Frequency	Percent	Valid Percent	Cumulative Percent
Very Low	22	9.4	9.4	9.4
Low	18	7.8	7.8	17.2
Neutral	30	12.9	12.9	30.1
High	52	22.5	22.5	52.6
Very High	48	20.8	20.8	73.4
Extremely High	61	26.4	26.4	100.0
Total	231	100.0	100.0	

Table 1 present students' perceptions regarding their exposure to and experience of PBL in Geometry lessons. The findings suggest that most of pupils perceived a high level of engagement with PBL practices. Specifically, 161 students (69.7%) rated their experience of PBL as high, very high, or extremely high, while 40 students (17.2%) reported low or very low levels of exposure. A further 30 students (12.9%) remained neutral.

The results indicate that majority of students' learning activities were connected to PBL related in geometry lessons, which include opportunities for pupils to collaborate, inquire, problem solve and be active in the learning process. There were, however, reports that some students had low levels of exposure which suggests differences in the amount of PBL practices that were experienced in learning environments. This could be because of

variations in classroom practices, teacher readiness, resources available, or the level of consistency in the use of PBL across schools.

The findings are consistent with Mutua, Miheso-O'Connor, and Ondigi (2023), who observed that learner-centered approaches are increasingly being incorporated into Kenyan secondary school instruction, although variations in implementation continue to exist.

Table 2: Teacher Implementation of PBL in Geometry in Schools (N=36)

Level	Frequency	Percent	Valid Percent	Cumulative Percent
Very Low	12	33.3	33.3	33.3
Low	8	22.2	22.2	55.5
Neutral	4	11.1	11.1	66.6
High	6	16.7	16.7	83.3
Very High	4	11.1	11.1	94.4
Extremely High	3	5.6	5.6	100.0
Total	36	100.0	100.0	

Source: Teacher questionnaire data.

Table 2 presents findings on teachers' reported implementation of PBL in Geometry lessons based on responses obtained from the teacher questionnaire (N=36). The findings reflect the frequency with which teachers reported using PBL strategies, including problem-based tasks, collaborative learning activities, inquiry approaches, and facilitation of learner-centred activities during Geometry instruction.

Table 2 suggested that the level of PBL implementation among teachers in the sampled schools was generally low. More than half of the teachers (55.5%) reported very low or low levels of implementation, while only 33.4% indicated high, very high, or extremely high levels of implementation. This suggests that although some teachers have integrated PBL strategies into geometry lessons, a considerable proportion continue to rely on conventional teacher-centred instructional approaches.

The results suggest the teachers need further assistance to successfully incorporate PBL in their Geometry teaching. This can include ongoing professional development, provision of suitable teaching materials, and support from the administration to help with the shift from conventional teaching methods to student-centered approaches. The results are congruent with the findings of Batiibwe (2024) which revealed that though PBL has a positive impact on mathematics learning, many secondary maths teachers find it difficult to effectively implement PBL in mathematics lessons because of inadequate training, insufficient resources, and inadequate institutional support.

Difference in Geometry Achievement between Students Taught Using PBL and Those Taught Using Conventional teaching.

This section addresses the second research objective, which intended to ascertain the difference in Geometry achievement between pupils taught utilizing PBL and those taught through conventional teaching methods in selected public secondary schools in Kiambu Sub-County, Kenya. Students' achievement was measured utilizing the Geometry Achievement Test (GAT), which was administered before and after the intervention. The data were analyzed via descriptive and inferential statistics to ascertain if notable differences existed in Geometry achievement between pupils exposed to PBL and those taught utilizing conventional teaching methods. The descriptive analysis presents the mean performance of pupils in the experimental and control groups, whereas the inferential analysis determines whether the observed variances between the two groups were statistically substantial. An independent-samples t-test was used to ascertain the statistical significance of the differences in mean Geometry achievement between the experimental and control groups.

Achievement in Geometry between Students Taught Using PBL and Those Taught Using Conventional teaching methods.

The second research objective sought to determine the variance in Geometry achievement between pupils taught utilizing PBL and those taught via conventional teaching methods in selected public secondary schools in Kiambu Sub-County, Kenya. Data were gathered utilizing the Geometry Achievement Test (GAT), which was administered as a pre-test and post-test. An independent-samples t-test was conducted to ascertain whether the variances in achievement between the experimental and control groups were statistically substantial. The findings are presented below. The maximum possible score for each test was 25 marks.

Table 3: Treatment and Control Group performance (Boys' School)

Group	N	Pre-test Mean	Post-test Mean
Experimental	33	2.79	13.30
Control	43	3.25	3.69

Table 3 indicate a substantial difference in Geometry achievement between the experimental and control groups. Students in the experimental group, who were taught using PBL, improved their mean score from 2.79 in the pre-test to 13.30 in the post-test. In contrast, students in the control group, who were taught through conventional teaching methods, showed only a slight advancement from a mean of 3.25 to 3.69. The greater improvement observed amongst pupils in the experimental group suggests that exposure to PBL was associated with higher Geometry achievement than conventional teaching methods. The findings are congruent with Bell (2010), who reported that PBL can enhance students' understanding and performance through active and learner-centred learning experiences.

Table 4: Experimental and Control Group performance (Girls' schools)

Group	N	Pre-test Mean	Post-test Mean
Experimental	41	1.56	45.63
Control	45	3.11	3.09

Table 4 show a strong improvement in Geometry performance among girls in the experimental group. Their mean score improved from 1.56 in the pre-test to 45.63 in the post-test after being taught using PBL. In contrast, the control group recorded almost no change, with a slight drop from 3.11 to 3.09. This indicates that pupils who learned through PBL performed much better than those who did not. It can be observed that learner-centered and practical teaching approaches support better understanding of Geometry concepts, especially for girls. The implication is that schools should encourage more use of PBL to improve achievement. These findings agree with Hmelo-Silver (2019), who notes that PBL promotes deeper understanding and improves students' learning outcomes by engaging them actively in inquiry, collaboration, and problem solving.

Table 5: Experimental and Control Group performance (Mixed schools)

Group	N	Pre-test Mean	Post-test Mean
Experimental	31	2.23	14.87
Control	38	1.82	3.09

Table 5 show that students in mixed schools who were taught utilizing PBL recorded a notable improvement in Geometry performance. The experimental group improved from a pre-test mean of 2.23 to a post-test mean of 14.87, while the control group evinced only a small improvement from 1.82 to 3.09. This indicates that learners exposed to PBL achieved better learning gains. It can be observed that interactive and learner-centered teaching methods support stronger understanding of Geometry concepts across different school settings. The implication is that incorporating PBL can enhance students' engagement and academic achievement in mathematics. These findings align with Hmelo-Silver (2023), who reports that inquiry-based and problem-centered learning approaches improve students' conceptual understanding and performance in mathematics by encouraging active participation and deeper thinking.

To ascertain whether there was a statistically substantial variance in Geometry performance between students taught via PBL and those taught utilizing Conventional methods, an Independent Samples t-test was performed. This assessment was suitable as it evaluates the average scores of two separate cohorts (experimental and control groups) to ascertain if any detected disparity is statistically significant rather than attributable to random variation. The

results of the t-test were used to establish whether the implementation of PBL had a substantial effect on pupils' achievement in Geometry. The findings are displayed in Table 6 below:

Table 6: Independent Sample T-test of Differences in Pre-Test and Post-Test Geometry Achievement Scores between the Experimental and Control Groups

		Levene's Test for Equality of Variances		**t-test for Equality of Means**		
		F	Sig.	t	df	Sig. (2-tailed)
Pre-test scores/25	Equal variances assumed	5.580	.020	1.201	98	.233
	Equal variances not assumed			1.201	90.243	.233
Post-test scores/25	Equal variances assumed	28.332	.000	-7.303	98	.000
	Equal variances not assumed			-7.303	62.465	.000

Table 6 suggest that there was no statistically substantial variance in Geometry achievement between the experimental and control groups at the pre-test stage, $t(98) = 1.201$, $p = .233$. Since the p-value was >.05 significance level, the null hypothesis of insignificant variance at baseline was not rejected. This indicates that the two groups did not vary substantially in their Geometry achievement before the intervention.

However, the post-test results demonstrated a statistically substantial variance between the experimental and control groups, $t = -7.303$, $p < .001$. The negative t-value reflects the direction in which the group means were entered into the analysis; the descriptive statistics indicate that the experimental group achieved higher post-test scores than the control group. Consequently, the null hypothesis of no substantial variance in post-test Geometry achievement was rejected.

Collectively, the findings suggested that the experimental and control groups were statistically comparable at the pre-test stage but differed significantly after the intervention. The variance in the pupil's performance between pre-test and post-test for students taught by PBL shows a significant increase in Geometry achievement for students taught by PBL, implying that PBL was related to improving students' achievement in Geometry in such a way that it can be inferred that there is an enhancement in students' performance in Geometry via the utilization of PBL. Therefore, the results implied that there was a

statistically substantial variance between the Geometry achievement of pupils who learned by using PBL and those who were conventionally taught. This is congruent with what Mensah et al (2022) reported that PBL implementation and other forms of active learning can enhance pupil's mathematics achievement and understanding of mathematics over traditional methods of teaching mathematics.

CONCLUSION AND RECOMMENDATIONS

First, the study concludes that PBL had been integrated into Geometry teaching to a considerable extent, particularly from the students' perspective. However, teacher-reported implementation was generally lower, indicating that PBL was not consistently or uniformly integrated across the sampled schools. The difference between students' reported exposure and teachers' reported implementation suggests variations in the extent and manner in which PBL was applied in Geometry classrooms.

Second, the study concludes that pupils taught through PBL achieved substantially higher post-test Geometry scores than students taught through conventional teaching methods. Since the two groups did not differ significantly at the pre-test stage, the higher post-test performance of the experimental group provides evidence that PBL was associated with improved Geometry achievement among the students involved in the study.

Recommendations

Based on the findings and conclusions of the study, the subsequent recommendations are made:

School administrators should strengthen support for PBL by providing teachers with opportunities for professional development, adequate instructional materials, and sufficient time to plan and implement problem-based lessons.

The Ministry of Education, through relevant teacher professional development programmes such as CEMASTEA and SMASSE, should provide continuous, practice-oriented training on PBL in Geometry, with particular emphasis on classroom management, time management, learner scaffolding, and facilitation of problem-solving activities.

Teacher training institutions should strengthen the preparation of pre-service teachers in PBL by incorporating practical PBL experiences and requiring student teachers to demonstrate competence in facilitating learner-centred problem-solving activities during teaching practice.

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