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The Impact of the Flipped Classroom and the van-Hiele Model Approaches on Secondary School Students' Geometry Achievement in North Central Nigeria

***[1]Usman, H., [2]Kure, I. D., [1]Salahudeen, Y., [3]Wangwa, A., & [3]Usman, H.**
[1]Department of Science Education, Abdulkadir Kure University, Minna, Nigeria
[2]Department of Science Education, Ibrahim Badamasi Babangida University, Lapai, Nigeria
[3]Niger State Teacher Professional Development Institute, Minna, Nigeria

***Corresponding author email**: babanibro73@gmail.com

Abstract
This study examined the effects of three instructional strategies—the flipped classroom approach (FCA), van Hiele model (VHM), and conventional teaching methods—on secondary school students' geometry achievement in North Central, Nigeria. Three research questions and corresponding hypotheses guided the study. A three-by-two (3x2) quasi-experimental factorial design was employed. The study population comprised 139,168 Senior Secondary School students in North Central Nigeria. Using a multistage sampling technique, 348 students from twelve co-educational secondary schools were selected and assigned to three groups: Experimental Group I (FCA), Experimental Group II (VHM), and a Control Group (conventional lecture method). The experimental groups were taught using the flipped classroom approach and the van Hiele model, respectively, while the control group received conventional instruction on the same geometry topics. Data were collected using a 30-item Geometry Achievement Test (GAT). A reliability coefficient of 0.84 was obtained for the GAT. Data were analyzed using Two-way Analysis of Variance (ANOVA), with hypotheses tested at a 0.05 significance level. The results revealed significant differences in mean achievement scores among students taught using FCA, VHM, and conventional methods. Additionally, an interaction effect was observed between the instructional methods and gender. The findings have significant implications for curriculum development and improving instructional strategies in mathematics education. The study offers valuable insights for educators aiming to enhance geometry learning experiences and outcomes through effective teaching approaches.

Keywords: Achievement, Approaches, Flipped-classroom, Geometry, Students, van-Hiele Model

Introduction

Geometry is the bedrock of mathematics education, essential for developing students' spatial reasoning, problem-solving skills, and logical thinking. Its applications in daily life are vast, making it a powerful problem-solving tool. The knowledge and use of geometry date back to ancient Egyptian civilization, where it played a crucial role in the construction of magnificent temples, palaces, dams, and bridges (Ostriker & Mitton 2024). Today, geometry's influence extends beyond construction and measurements, impacting fields such as engineering, Biochemistry, Modeling, Design, Computer graphics, and Typography (Teplá et al., 2022). Researchers have recognised its significance in mathematics education and explored ways to enhance geometry learning. In the 1960s, Dutch educators Dina Van Hiele-Geldof and Pierre Van Hiele investigated why children struggle with geometry and developed instructional methods to improve comprehension (Mahlaba & Mudaly, 2022). Recent studies have demonstrated that geometry constitutes a significant portion of secondary mathematics curricula globally, with approximately 25–30% of instructional content in grades 9 and 10 dedicated to geometric concepts (Baah-Duodu et al., 2020; Khalil et al., 2024; Naidoo & Kapofu, 2020; Yohannes & Chen, 2023). This emphasis is even more pronounced in national contexts such as Nigeria, where geometry accounts for 38% of the mathematics curriculum (Accra-Jaja et al., 2023; Garba, 2024; Ndanusa et al., 2023). Furthermore, an analysis of the Senior School Certificate Examination (SSCE) syllabus reveals that nearly 45% of assessed topics are geometry-related, underscoring its centrality in high-stakes assessments (West African Examinations Council [WAEC], 2014). Given its foundational role, predominantly at the junior levels, geometry plays a crucial role in building a foundation for more advanced mathematical concepts, making it an important part of the mathematics curriculum in Nigerian secondary schools. Therefore, students must develop a strong grasp of basic geometric shapes and their properties, applying this knowledge to formal proofs and problem-solving using deductive reasoning. This solid foundation equips students with the flexibility needed for higher-level mathematics.

A key framework that enhances this learning process is the van Hiele model, developed by Pierre van Hiele and Dina van Hiele-Geldof in the 1950s. This model outlines five levels of geometric thinking—Recognition, Analysis, Order, Deduction, and Rigor—which students progress through based on experience and instruction rather than age. To advance through these levels, students require structured exposure to geometric concepts, facilitated by five instructional phases: Information, Guided Orientation, Explicitation, Free Orientation, and Integration. Research by Adeniji and Baker (2022) and González et al. (2022) supports the notion that these phases are essential for students to transition between levels effectively. Understanding the van Hiele model provides valuable insights into cognitive development in geometry and underscores the importance of instructional strategies tailored to students' learning progression. In this regard, comparing the van Hiele model with the Flipped Classroom approach presents a promising avenue for enhancing secondary school students' achievement in geometry. Both models emphasize the role of structured learning experiences in fostering deeper conceptual understanding. While the van Hiele model provides a framework for the progression of geometric thought, the Flipped Classroom approach offers a pedagogical strategy that can support this progression by optimizing instructional time and student engagement.

The Flipped Classroom approach is an educational strategy that inverts traditional teaching methods. In a flipped classroom, instructional content is delivered outside of class, typically through video lectures or other digital resources, allowing classroom time to be devoted to active learning, discussions, and hands-on activities. This approach encourages students to engage with the material at their own pace outside of class, fostering a more personalized learning experience. During class, students can apply their knowledge with the guidance of the instructor, enhancing their understanding through collaborative and practical activities. The flipped classroom model has been shown to increase student engagement, improve critical thinking skills, and provide opportunities for more individualized support. According to Abuhmaid and Mohammad (2020), the flipped classroom is a unique learning approach that reverses the traditional model, allowing classroom activities to take place outside the classroom, creating a blended learning experience, and homework activities occur during class time. This means that teachers record lessons to be watched by students before class. The model divides learning into two main components: interactive group activities inside the classroom and individual computer-based learning outside the classroom (Huber et al., 2022). In a flipped classroom, web-based videos are often assigned for homework, whereas the class period is devoted to problem-solving, dialogues, and other interactive activities (Ajmal & Hafeez, 2021). It is important to understand that a flipped classroom is more than just rearranging activities; it's an expansion of the curriculum that offers new ways of learning. (Abu-Shanab, 2020). Built on the principles of constructivist teaching, this approach focuses on problem-based learning, teamwork, research, and creative projects (Bada & Olusegun, 2015). In this model, the teacher takes on the role of a guide or coach, helping students learn by creating supportive activities and environments that build on their existing knowledge (Atta & Brantuo, 2021). Teachers design lessons to encourage students to actively engage in constructing their understanding (Kumar, 2018)

The efficiency of the Flipped Classroom Approach (FCA) and the Van Hiele Model (VHM) in enhancing students' mathematics and geometry performance has been widely examined in the literature. Globally, studies such as Uy (2022), Harmini et al. (2022), Mubarok et al. (2019), Elian and Hamaidi (2021), Wei et al. (2020), Khadjieva and Khadjikhanova (2019), and Karadag and Keskin (2017) have demonstrated FCA's superiority over traditional methods, highlighting its ability to improve engagement, achievement, and retention. In Nigeria, research by Efiuvwere and Fomsi (2019) and Omile et al. (2021) suggests that FCA increases students' interest and academic performance in mathematics. Specifically, studies conducted in Zaria, Kaduna State, and Igbo-Etiti, Enugu State, found that FCA significantly improved geometry achievement and interest, with mixed findings on gender-based retention (Efiuvwere & Fomsi, 2019; Omile et al., 2021). To further promote innovative instructional strategies, researchers recommend integrating FCA into teacher training programs through professional bodies like MAN (Mathematical Association of Nigeria) and STAN (Science Teachers Association of Nigeria).

Similarly, the Van Hiele Model has been effective in improving geometric reasoning and problem-solving skills. In Nigeria, Usman and Ogunlade (2020), Usman et al. (2020) found that students taught using the Van Hiele Model outperformed those in conventional classrooms. Studies in South Africa (Alex & Mammen, 2018), Turkey (Erdogan & Durmus, 2009), and Indonesia (Olkun et al., 2014) further confirm its effectiveness, with female students showing greater gains in spatial visualization. A study in Spain also demonstrated its utility in assessing complex mathematical concepts among undergraduate Computer Engineering students, though students struggled with logical relationships, indicating a need for refined instructional strategies.

Overall, both FCA and the Van Hiele Model are effective in improving students' achievement, interest, and retention in mathematics. While FCA enhances engagement and long-term retention, the Van Hiele Model provides a structured framework for cognitive development. However, research on their application in Nigerian secondary schools remains limited. Further studies are needed to explore their long-term effects on conceptual understanding, retention, and gender-based performance in geometry. Integrating both approaches could offer a comprehensive strategy for teaching mathematics, addressing both content delivery and cognitive development.
As a result, it's essential to adjust teaching methods, learning activities, and the ways of assessment of learning outcomes (Gravemeijer, 2020). Teachers offer support to help students expand their potential and develop key metacognitive skills, like reflective thinking and problem-solving. This guidance helps learners process, adapt to, and reflect on new and sometimes conflicting ideas.

Given the above, this study aims to compare the Flipped Classroom approach and the van Hiele model on Secondary School Students' achievement in geometry. By examining the effectiveness of these instructional methods, the research seeks to provide insights into how teacher education programs can be enhanced to better prepare future educators for teaching geometry.

Aim and Objectives of the Study

This study aims to determine the impact of the flipped classroom and the van Hiele Model approaches on secondary school students' geometry achievement in North Central Nigeria. **Precisely, the research objectives are:**

1. Investigate how different teaching methods impact Secondary School students' achievement in Geometry.
2. Examine how gender influences Secondary School students' performance in Geometry.
3. Explore the combined influence of teaching methods and gender on Secondary School students' achievement in Geometry

Research Questions

To evaluate pre-service mathematics teachers' achievement in geometry, the following research questions have been formulated:

1. Does the teaching method have an impact on Secondary School students' achievement in Geometry?
2. Does gender play any role in Secondary School students' performance in Geometry?
3. Is there interaction between teaching method and gender affecting Secondary School students' achievement in Geometry?

Null Hypotheses

The null hypotheses were formulated from the corresponding research questions raised above.
The null hypotheses of the study were as follows:

Ho_1: There is no significant main effect of teaching method on Secondary School Students' Geometry Achievement.

Ho_2: There is no significant main effect of gender on Secondary School Students' Geometry Achievement.

Ho_3: There is no significant interaction effect of teaching method and gender on Secondary School Students' Geometry Achievement.

Materials and Methods

The study employs a three-by-two (3x2) quasi-experimental factorial design with a pre-test and post-test non-equivalent group design. This approach uses non-randomized groups, as the researcher could not randomly assign subjects due to the use of intact classes for administering the treatment. The study population consists of

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senior secondary two (SSII) students in the North Central region, with a total of 139,168 students. A sample of 348 SSII students was selected, including 229 males and 119 females. To ensure proper representation of the population, a cluster random sampling technique was used to select participants from intact classes in the schools. This method involves choosing clusters that contain multiple members from the population (Uzoagulu, 1998). The Geometry Achievement Test (GAT) was the instrument used to gather data. The test was validated by experts, and its reliability was determined through a test-retest method during a pilot study conducted with a separate group outside the target population. The two-week interval pilot test produced a Pearson Product-Moment Correlation Coefficient (PPMC) of 0.84, indicating that the instrument was reliable. Data analysis was carried out using inferential statistics, specifically Analysis of Variance (ANOVA), to test the hypotheses at a 0.05 level of significance.

Results

Research Question 1: Does the teaching method have an impact on Secondary School students' achievement in Geometry?

Table 1: Mean and Standard Deviation of Pre-test and Post-test Achievement Scores of Experimental I, II and Control Group

Group	N	Pretest X	SD	Post-test X	SD	Mean difference
Experimental Group I	116	31.78	14.19	61.47	8.74	29.69
Experimental Group II	106	46.86	11.66	62.30	10.44	15.44
Control Group	126	42.18	14.37	45.47	10.74	3.29

Table 1 presents the mean and standard deviation of achievement scores for Experimental Group I, Experimental Group II, and the Control Group at both the pre-test and post-test stages. The data indicate that for Experimental Group I (FCM), the mean and standard deviation scores were 31.78 (SD = 14.19) at the pre-test and 61.47 (SD = 8.74) at the post-test. This reflects a mean difference of 29.69 in favor of the post-test. Similarly, Experimental Group II (MM) recorded a mean of 46.86 (SD = 11.66) at the pre-test and 62.30 (SD = 10.44) at the post-test, leading to a mean difference of 15.44 in favor of the post-test. For the Control Group, which was taught using traditional lecture methods, the mean and standard deviation scores were 42.18 (SD = 14.37) at the pre-test and 45.47 (SD = 10.74) at the post-test, yielding a mean difference of 3.29 in favor of the post-test. From these results, Experimental Group I showed the highest mean gain (29.69), followed by Experimental Group II (15.44), while the Control Group had the lowest gain (3.29). Given these differences in achievement scores, Hypothesis I was tested at a 0.05 significance level to determine whether the observed variations were statistically significant. To analyze this, a Two-way ANOVA test was conducted, with the results presented in Table 3.

Research Question 2: Does gender play any role in Secondary School students' performance in Geometry?

Table 2: Mean and Standard Deviation of Pre-test and Post-test Achievement Scores by Gender

Group	N	Pretest Mean	SD	Post-test Mean	SD	Mean difference
Male	229	41.36	14.40	59.20	10.56	17.84
Female	119	37.79	15.51	48.75	13.35	10.96

Table 4.2 presents the pretest and post-test mean scores, standard deviations (SD), and mean differences for male and female participants. In the pretest, males had a mean score of 41.36 (SD = 14.40), whereas females had a lower mean score of 37.79 (SD = 15.51). This indicates that, on average, males performed slightly better than females before the intervention. After the intervention, males showed a substantial improvement, with a post-test mean score of 59.20 (SD = 10.56), compared to females who had a post-test mean score of 48.75 (SD = 13.35). The mean difference between the pretest and post-test scores was 17.84 for males and 10.96 for females,

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suggesting that males exhibited a greater improvement compared to their female counterparts. The results indicate that while both groups benefited from the intervention, the effect was more pronounced among males. Further statistical analysis, such as a t-test or ANOVA, would be needed to determine if these differences are statistically significant.

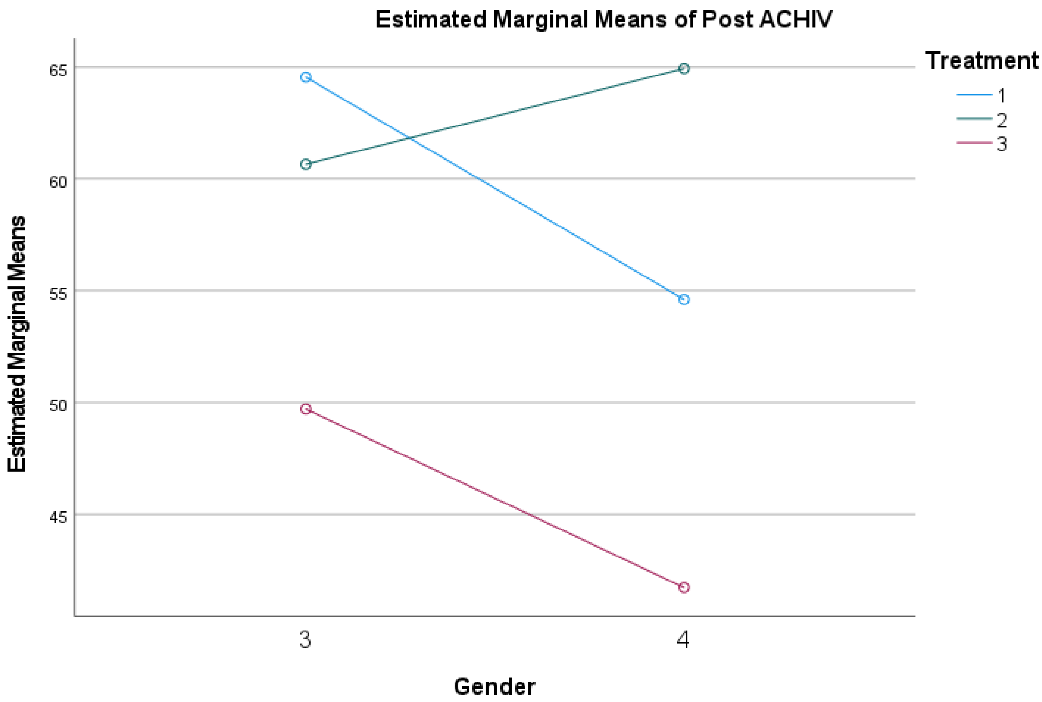

Figure 1. Interaction effect between treatment and gender on achievement.

Table 3: Summary of Analysis of ANOVA result of GAT Posttest Achievement Scores of Experimental and Control Groups

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Model	1101776.119[a]	6	183629.353	2095.408	.000	.974
Treatment	15897.566	2	7948.783	90.704	.000	.347
Gender	1275.906	1	1275.906	14.559	.000	.041
Treatment * Gender	1938.555	2	969.277	11.060	.000	.061
Error	29970.881	342	87.634			
Total	1131747.000	348				

a. R Squared = .974 (Adjusted R Squared = .973)

The table shows the two-way analysis of variance (ANOVA) comparison of Post-test scores for the Experimental Groups and the Control Group. An examination of the table indicate a significant difference in the post-test scores for the main effect of treatment (i.e., teaching methods), $F(2,342) = 90.70$, $p < 0.05$, partial eta square = .34. Also, the main effect of gender on Secondary School Students' achievement in geometry was found to be significant given by $F(2,342) = 14.55$, $p < 0.05$, partial eta square = .041 which implied that there is significant main effect of gender on the post-test achievement scores. Similarly, facts emerging from the table revealed a significant interaction effect of treatment and gender on achievement in geometry post-test scores, $F(1,342) = 11.06$, $p < 0.05$, partial eta square = 15.

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Discussion

The results of the two-way ANOVA provide valuable insights into the effectiveness of the Flipped Classroom Approach (FCA) and the Van Hiele Model (VHM) in enhancing students' performance in mathematics and geometry. The empirical review highlights prior research that has consistently demonstrated the advantages of these instructional approaches over traditional teaching methods. The current study's findings align with these previous works, reinforcing the efficacy of FCA and VHM in improving student achievement, engagement, and retention.

The analysis reveals a significant main effect of instructional treatment on students' mathematics performance ($F = 90.704$, $p < .001$, partial eta squared = .347). This suggests that the instructional approach—whether FCA, VHM, or a combination—had a substantial impact on students' learning outcomes. The partial eta squared value of .347 indicates a large effect size, meaning that nearly 35% of the variance in students' performance can be attributed to the teaching method employed. This finding supports previous research by Uy (2022), Elian and Hamaidi (2021), and Omile et al. (2021), who reported that FCA significantly enhances students' achievement, interest, and long-term retention. Similarly, the positive effect of the Van Hiele Model aligns with studies conducted by Erdogan and Durmus (2009), which showed that students taught using VHM demonstrated superior geometric reasoning and problem-solving skills compared to their peers in conventional classrooms. The analysis also indicates a significant main effect of gender on students' performance ($F = 14.559$, $p < .001$, partial eta squared = .041). While the effect size is smaller compared to the instructional treatment, it still suggests that gender plays a role in students' mathematics achievement. This result is consistent with findings from Olkun et al. (2014) and Usman and Ogunlade (2020), who noted that female students often show greater gains in spatial visualization when exposed to structured instructional models like the Van Hiele Model. However, mixed findings regarding gender-based retention in FCA (Efiuvwere & Fomsi, 2019) suggest that further research is needed to understand gender-specific learning preferences in mathematics education.

Interaction Effect of Treatment and Gender

The interaction effect between treatment and gender is also significant ($F = 11.060$, $p < .001$, partial eta squared = .061), indicating that the effectiveness of FCA and VHM varies based on gender. This finding suggests that while both instructional approaches are beneficial, their impact may differ for male and female students. The relatively small effect size (.061) implies that although gender influences the effectiveness of these teaching methods, the primary determinant of student performance remains the instructional approach. This interaction effect supports previous studies by Alex and Mammen (2018) and a study in Spain, which found that while both male and female students benefited from FCA and VHM, female students showed greater improvements in specific cognitive skills like spatial visualization.

Implications for Mathematics Instruction

The high R-squared value (.974) suggests that the combination of treatment, gender, and their interaction explains nearly 97.4% of the variance in students' mathematics performance. This indicates that FCA and VHM are highly effective instructional strategies. Given these findings, there is a strong case for integrating these methods into the Nigerian secondary school curriculum.

For Teachers and Educators: The results emphasize the need for teachers to adopt innovative instructional approaches that actively engage students and foster deeper cognitive development. The structured nature of the Van Hiele Model can enhance students' logical reasoning and problem-solving skills, while FCA provides an interactive learning environment that promotes self-directed learning and retention.

For Policymakers: The findings support the recommendation to integrate FCA and VHM into teacher training programs through professional organizations such as the Mathematical Association of Nigeria (MAN) and the Science Teachers Association of Nigeria (STAN). For Further Research: While this study confirms the effectiveness of these instructional approaches, additional research is needed to explore their long-term impact on conceptual understanding, gender differences in learning outcomes, and retention rates over time.

Conclusion

This study provides empirical evidence that both FCA and VHM significantly enhance students' mathematics performance, with a notable influence of gender on learning outcomes. The significant interaction effect suggests that instructional strategies should be tailored to accommodate gender differences in cognitive development and learning preferences. Future research should explore hybrid models that integrate FCA and VHM to maximize their combined benefits in improving mathematics education.

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