

Comparative Effects of Virtual Reality and Traditional Video-Based Learning on Immediate Achievement and Concept Retention in Senior Secondary School Physics in Rivers State, Nigeria

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Abstract

This study compared VR-based and video-based learning in relation to students' immediate achievement and four-week delayed concept retention in Senior Secondary School Physics, focusing on electromagnetic-field concepts. A quasi-experimental pre-test/post-test non-equivalent group design was adopted. The participants were 80 Senior Secondary 2 Physics students from two purposively selected secondary schools in Rivers State, Nigeria. Four intact classes were allocated to either a VR-based learning condition or a video-based learning condition. Both groups studied equivalent content for four weeks. Data were collected using a 40-item Physics Concept Retention Test administered as a pre-test, immediate post-test and four-week delayed post-test. The data were analysed using descriptive statistics and Analysis of Covariance, with pre-test scores serving as the covariate. Students in the VR-based learning group obtained higher mean scores than those in the video-based learning group on both the immediate and delayed post-tests. The instructional method-by-gender interaction on delayed concept-retention scores was not statistically significant. The findings provide preliminary evidence that interactive three-dimensional learning may support the study of abstract and spatially demanding Physics concepts. However, the use of purposively selected schools and intact classes limits causal and generalisable conclusions. Further research involving larger samples, more schools, monitored exposure and longer follow-up periods is recommended.

Keywords: Virtual reality, video-based learning, immediate achievement, concept retention, Physics education, electromagnetic fields.

Introduction

The rapid development of digital technologies has created new possibilities for improving the teaching and learning of Science, Technology, Engineering, and Mathematics (STEM) subjects. Educational technologies can support the visualisation and exploration of concepts that are difficult to observe directly, thereby complementing conventional classroom instruction. This is particularly relevant in Nigerian schools, where inadequate laboratory facilities and limited

instructional resources may constrain students' opportunities to engage with practical and abstract scientific concepts (Ajemba, 2024; Oginni, Awobodu, and Olusegun, 2025). Recent initiatives have similarly advocated AI-driven approaches to widen access to STEM education for underserved learners (Nweje, 2026).

Virtual Reality (VR) is an emerging technology that may help address some of these challenges. VR provides three-dimensional environments in which learners can explore and interact with simulated objects, processes and phenomena. Its immersive and interactive features may help learners develop clearer mental representations of concepts that are spatially complex or difficult to observe directly (Makransky and Petersen, 2021; Pottle, 2019). In Physics, these affordances may be particularly useful for topics involving invisible forces, dynamic processes and spatial relationships. VR has similarly been integrated with peer-assessment strategies to support science learning in other subject domains (Chang, Hsu, and Jong, 2020), and such tools are becoming increasingly integrated into mainstream classroom instruction (Oigara, 2018). Related immersive technologies such as augmented reality have also been associated with a range of educational benefits (Diegmann, Schmidt-Kraepelin, van den Eynden, and Basten, 2015; Lytvynova and Soroko, 2023), and a growing body of work associates VR and AR tools with improved student performance across STEM fields more broadly (Pireva Nuci and Shatri, 2026).

Electromagnetic-field concepts present notable learning difficulties because electric and magnetic fields cannot be observed directly in the same way as visible physical objects. Students are expected to understand field direction, distribution, intensity, magnetic field lines, solenoids, current direction and electromagnetic induction. These concepts require learners to construct mental representations of relationships that are not readily visible through ordinary classroom observation. Where laboratory resources are limited, the difficulty of providing meaningful learning experiences may be increased (Ajemba, 2024; Oginni et al., 2025).

Video-based learning offers a relatively accessible means of presenting demonstrations, animations and explanations of Physics phenomena. It requires fewer technological resources than some immersive technologies and allows students to revisit instructional materials. However, conventional two-dimensional videos generally provide limited opportunities for learners to manipulate phenomena or explore spatial relationships from different perspectives. VR, in contrast, may provide a more interactive environment in which students can examine simulated field patterns, manipulate selected variables and observe corresponding changes. These features may support active engagement and conceptual understanding (Makransky and Petersen, 2021).

However, the potential value of VR should not be judged solely by students' immediate performance after instruction. A higher post-test score may indicate successful learning at the end of an intervention without demonstrating that the knowledge has been retained. Delayed

assessment therefore provides additional evidence of whether learning is maintained beyond the immediate instructional experience. Comparing immediate achievement with delayed concept retention can consequently provide a more comprehensive assessment of technology-supported Physics instruction.

Gender is another factor that may warrant consideration. Students may differ in their previous experiences with digital technologies, confidence, engagement and learning opportunities. These differences could potentially influence their responses to technology-supported instruction. Examining the interaction between instructional method and gender may therefore indicate whether the effectiveness of the instructional approaches varies across male and female students. Any claims about gender differences should, however, be supported by relevant gender-and-technology or Physics-education literature.

Despite increasing interest in immersive learning, empirical evidence comparing VR and video-based learning using both immediate and delayed measures remains limited, particularly in Nigerian secondary-school Physics. Evidence is especially limited for electromagnetic-field concepts, where students must understand abstract and spatially demanding relationships. This study therefore compared VR-based and video-based learning in relation to students' immediate achievement and four-week delayed concept retention in Senior Secondary School Physics in Rivers State, Nigeria. It also examined whether instructional method interacted with gender in relation to delayed concept-retention performance.

Statement of the Problem

Physics is important to scientific and technological development, yet many secondary-school students experience difficulty understanding abstract concepts involving invisible forces, spatial relationships, and dynamic processes. Electromagnetic-field concepts are particularly challenging because their patterns and interactions cannot be directly observed. Inadequate laboratory facilities and instructional resources may further limit opportunities for students to develop meaningful understanding of such concepts (Ajemba, 2024; Oginni et al., 2025). These constraints carry implications extending across STEM-dependent sectors such as agriculture and health (Olatunji and Akinola, 2023).

Video-based learning provides an accessible means of presenting demonstrations and visual explanations, but its two-dimensional format may offer limited opportunities for learners to interact with complex spatial relationships. VR provides a more immersive alternative by allowing students to explore and manipulate three-dimensional representations of physical phenomena. Although previous studies have reported promising learning outcomes associated with VR, evidence comparing VR directly with video-based learning in Nigerian secondary-school Physics remains limited. Furthermore, immediate post-test performance does not necessarily demonstrate that students retain what they have learned. There is therefore a need to determine whether VR and video-based learning differ in their effects on both immediate

achievement and delayed concept retention. It is also important to establish whether the effectiveness of these instructional approaches differs according to gender.

The problem addressed by this study, therefore, was the limited empirical evidence on the comparative effectiveness of VR-based and video-based learning for immediate achievement and delayed retention of electromagnetic-field concepts among Senior Secondary School Physics students in Rivers State. The study consequently compared the two instructional approaches and examined their interaction with gender on students' delayed concept-retention performance.

Purpose of the Study

The purpose of this study was to compare the outcomes associated with VR-based and video-based learning on students' immediate achievement and delayed concept retention in Senior Secondary School Physics, with emphasis on electromagnetic-field concepts in Rivers State.

Specifically, the study sought to:

1. compare the immediate achievement scores of students exposed to VR-based and video-based learning;
2. compare the delayed concept-retention scores of students exposed to VR-based and video-based learning; and
3. determine the interaction effect of instructional method and gender on students' delayed concept-retention scores.

Research Questions

1. What difference exists in the mean immediate achievement scores of students exposed to VR-based and video-based learning?
2. What difference exists in the mean delayed concept-retention scores of students exposed to VR-based and video-based learning?
3. What interaction effect exists between instructional method and gender on students' delayed concept-retention scores?

Research Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

1. There is no significant difference in the mean immediate achievement scores of students exposed to VR-based and video-based learning.
2. There is no significant difference in the mean delayed concept-retention scores of students exposed to VR-based and video-based learning.
3. There is no significant interaction effect between instructional method and gender on students' delayed concept-retention scores.

Materials and Methods

The study adopted a quasi-experimental pre-test/post-test non-equivalent group design involving 80 Senior Secondary 2 (SS2) Physics students from two purposively selected secondary schools in Obio/Akpor Local Government Area, Rivers State, Nigeria, during the 2025/2026 academic session. Four intact classes were assigned to VR-based and video-based learning conditions, with 40 students in each group. The schools were selected based on the availability of digital-learning facilities. Students were not individually randomised.

The VR group learned through three-dimensional simulations of magnetic-field lines, solenoid behaviour, current direction and electromagnetic induction, while the video group used two-dimensional instructional videos covering the same content. Both conditions were standardised in curriculum content, objectives and instructional duration and implemented for four weeks.

Data were collected using a 40-item Physics Concept Retention Test (PCRT), validated by experts and pilot-tested, with a KR-20 reliability coefficient of 0.70. The instrument was administered as a pre-test, immediate post-test and four-week delayed post-test.

Data were analysed using means, standard deviations and Analysis of Covariance (ANCOVA), with pre-test scores as the covariate. Separate ANCOVA models examined immediate achievement and delayed retention, while the gender model included instructional method, gender and their interaction. ANCOVA assumptions were examined before analysis. Partial eta squared was used to estimate effect sizes, and unadjusted Cohen's *d* was calculated where appropriate. Hypotheses were tested at the 0.05 significance level.

Results and Analysis

Research Question 1: What difference exists in the mean immediate achievement scores of students exposed to VR-based and video-based learning?

Table 1: Descriptive Statistics for Immediate Achievement Scores by Instructional Method

Instructional Method	N	Mean	Std. Deviation
VR-based learning	40	78.45	6.12
Video-based learning	40	64.20	7.35

Table 1 shows that students exposed to VR-based learning obtained a higher mean immediate-achievement score ($M = 78.45$, $SD = 6.12$) than those exposed to video-based learning ($M = 64.20$, $SD = 7.35$), representing an unadjusted mean difference of 14.25 points in favour of the VR group.

Table 2: ANCOVA Summary of Immediate Achievement Scores by Instructional Method

Source	Type III SS	df	Mean Square	F	p
Pre-test	124.50	1	124.50	2.90	.092
Instructional method	3,842.15	1	3,842.15	89.68	< .001
Error	3,300.20	77	42.86	—	—
Corrected total	7,266.85	79	—	—	—

The ANCOVA revealed a statistically significant difference in immediate-achievement scores, $F(1, 77) = 89.68$, $p < 0.001$, partial $\eta^2 = 0.538$; H_{01} was therefore rejected. Students exposed to VR-based learning performed significantly better than those exposed to video-based learning. As both conditions were implemented in both schools, school confounding was limited, though intact classes mean pre-existing class-level differences cannot be entirely ruled out.

Research Question 2: What difference exists in the mean delayed concept-retention scores of students exposed to VR-based and video-based learning?

Table 3: Descriptive Statistics for Delayed Concept-Retention Scores

Instructional Method	N	Mean	Std. Deviation
VR-based learning	40	75.10	6.85
Video-based learning	40	58.45	8.12

Table 3 shows that students exposed to VR-based learning obtained a higher mean four-week delayed concept-retention score ($M = 75.10$, $SD = 6.85$) than those exposed to video-based learning ($M = 58.45$, $SD = 8.12$). The observed unadjusted mean difference was 16.65 points in favour of the VR-based learning group.

Table 4: ANCOVA Summary of Four-Week Delayed Concept-Retention Scores by Instructional Method

Source	Type III SS	df	Mean Square	F	p
Pre-test	98.20	1	98.20	2.45	.121
Instructional method	4,215.30	1	4,215.30	105.09	< .001
Error	3,088.60	77	40.11	—	—
Corrected total	7,402.10	79	—	—	—

The ANCOVA revealed a statistically significant difference in four-week delayed concept-retention scores, $F(1, 77) = 105.09$, $p < 0.001$, partial $\eta^2 = 0.577$; H_{02} was therefore rejected. Students exposed to VR-based learning obtained significantly higher delayed-test scores than those exposed to video-based learning, indicating the difference persisted four weeks after the intervention. As intact classes were used, pre-existing class-level differences cannot be completely ruled out.

Research Question 3: What interaction effect exists between instructional method and gender on students' delayed concept-retention scores?

Table 5: Mean Delayed Concept-Retention Scores by Instructional Method and Gender

Instructional Method	Gender	N	Mean	Std. Deviation
VR-based learning	Male	20	75.80	6.20
VR-based learning	Female	20	74.40	7.50
Video-based learning	Male	20	59.20	7.90
Video-based learning	Female	20	57.70	8.40

Table 5 shows that both male and female students exposed to VR-based learning obtained higher mean delayed concept-retention scores than their counterparts exposed to video-based learning. The differences between male and female students within each instructional condition were relatively small. An inferential analysis was therefore conducted to determine whether the interaction between instructional method and gender was statistically significant.

Table 6: ANCOVA of Four-Week Delayed Concept-Retention Scores by Instructional Method, Gender, and Their Interaction.

Source	Type III SS	df	Mean Square	F	p	Partial η^2
Pre-test	98.20	1	98.20	2.40	.125	.031
Instructional method	4,210.50	1	4,210.50	102.94	< .001	.579
Gender	18.20	1	18.20	0.44	.507	.006
Instructional method $\times$ Gender	2.50	1	2.50	0.06	.805	.001
Error	3,067.90	75	40.91	—	—	—
Corrected Total	7,397.30	79	—	—	—	—

Table 6 shows that the pre-test covariate was not statistically significant, $F(1, 75) = 2.40$, $p = 0.125$, partial $\eta^2 = 0.031$. However, instructional method had a statistically significant effect on students' four-week delayed concept-retention scores, $F(1, 75) = 102.94$, $p < 0.001$, partial $\eta^2 = 0.579$. The large effect size indicates that instructional method was strongly associated with differences in delayed concept-retention performance, with students exposed to VR-based learning obtaining higher mean scores than those exposed to video-based learning.

The main effect of gender was not statistically significant, $F(1, 75) = 0.44$, $p = 0.507$, partial $\eta^2 = 0.006$, indicating that delayed concept-retention scores did not differ significantly between male and female students after controlling for the other variables in the model. Similarly, the instructional method $\times$ gender interaction was not statistically significant, $F(1, 75) = 0.06$, $p = 0.805$, partial $\eta^2 = 0.001$. Therefore, the null hypothesis was not rejected. The finding indicates that the association between instructional method and delayed concept-retention performance did not vary significantly by gender within the study sample. However, this result should be interpreted cautiously and should not be taken as evidence that the two instructional methods are equally effective across genders in the wider population.

Discussion of Findings

Immediate Achievement

In relation to Research Question 1, the findings showed that students exposed to VR-based learning achieved significantly higher immediate post-test scores than those exposed to video-based learning. This difference may be associated with the interactive and three-dimensional features of the VR environment, which enabled students to visualise and manipulate representations of electromagnetic phenomena. Such experiences may have contributed to clearer mental representations, although mental representations were not directly measured in this study. The finding is consistent with the view that immersive and interactive learning environments may support engagement with abstract and spatially demanding concepts (Makransky and Petersen, 2021). However, because the study used intact classes, the result should be interpreted as a difference associated with the instructional conditions rather than definitive evidence that VR alone produced the higher achievement.

Delayed Concept Retention

In relation to Research Question 2, students exposed to VR-based learning obtained significantly higher scores on the four-week delayed concept-retention test than those exposed to video-based learning. Although performance declined in both groups after the immediate post-test, the VR-based learning group recorded the higher delayed-test mean. This suggests that the difference associated with the VR condition remained evident four weeks after the intervention. The finding may be related to the opportunity provided by VR for learners to interact with and examine three-dimensional representations of otherwise abstract electromagnetic phenomena. Nevertheless, the result represents performance on a single four-week delayed assessment and should not be interpreted as evidence of permanent or long-term retention.

Gender Interaction

In relation to Research Question 3, the findings showed no statistically significant interaction between instructional method and gender in relation to delayed concept-retention scores. Male and female students exposed to VR-based learning both obtained higher mean scores than their counterparts in the video-based learning group, while the differences between male and female students within each instructional condition were relatively small. This indicates that the study did not detect a significant gender-based difference in the relationship between instructional method and delayed concept retention. However, the finding should be interpreted cautiously because each gender-by-instructional-condition subgroup contained only 20 students. The non-significant interaction should therefore not be interpreted as proof that VR is equally effective across genders in the wider population.

Conclusion

This study compared VR-based and video-based learning in relation to students' immediate achievement and four-week delayed concept-retention performance in Senior Secondary School Physics, focusing on electromagnetic-field concepts. Students in the VR-based learning group obtained higher scores on both the immediate and delayed post-tests than those in the video-based learning group, indicating that the difference associated with the VR condition remained evident four weeks after the intervention.

The findings provide preliminary evidence that interactive three-dimensional learning may support students' understanding of abstract and spatially demanding Physics concepts. Nevertheless, the use of purposively selected schools and intact classes means that pre-existing school- and class-level differences cannot be completely excluded. The two instructional packages may also have differed in interactivity, learner control, feedback, immersion, novelty and opportunities for manipulation. The results should therefore be interpreted as differences associated with the instructional conditions, not as definitive proof that VR alone caused the observed outcomes.

The study did not detect a statistically significant interaction between instructional method and gender in relation to delayed concept-retention performance. This finding remains preliminary because only 20 students were included in each gender-by-method subgroup. The focus on one Physics topic, the four-week follow-up period, the marginal reliability of the assessment instrument and the limited treatment-fidelity information further restrict the generalisability of the findings.

Overall, VR-based learning may serve as a useful complement to video-based learning when teaching electromagnetic-field concepts. Wider implementation should begin with carefully evaluated pilot programmes supported by teacher training, adequate infrastructure and further research involving larger samples, more schools and classes, monitored exposure, stronger assessment procedures and longer follow-up periods.

Recommendations

Based on the findings and limitations of the study, the following recommendations are made:

1. VR should be considered particularly for Physics topics involving spatial relationships, invisible phenomena, simulation, and processes that are difficult to demonstrate using conventional resources.
2. Teachers should combine video-based explanations with VR-based exploration where appropriate, allowing students to benefit from both accessible visual instruction and interactive three-dimensional experiences.
3. Physics teachers should receive training in VR-supported lesson planning, learner guidance, assessment, classroom management, and basic technical troubleshooting.

4. Schools and education authorities should provide the necessary digital infrastructure, including suitable devices, electricity, maintenance, offline resources, and reliable access to instructional content.
5. Future studies should include more schools and intact classes in each instructional condition, larger samples, stronger treatment-fidelity procedures, monitored exposure and time-on-task, and longer delayed assessments to provide stronger evidence of retention and transfer.
6. Future research should further examine whether learner characteristics, including gender, prior digital experience, technology confidence, and learning readiness, influence students' responses to VR-based instruction.

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