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Effects of Virtual and Physical Laboratory Instruction on Retention in Electrical Circuits among Electrical Engineering Students in Polytechnic in North-East Nigeria

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Abstract

This study investigated the effects of virtual and physical laboratory instruction on the retention of electrical circuits concepts among National Diploma (ND) II Electrical Engineering students in polytechnics in North-East Nigeria. A pre-test, post-test non-equivalent group quasi-experimental design was employed, involving 194 students from four polytechnics, with 89 students in the virtual laboratory group and 105 in the physical laboratory group. Data were collected using a validated 50-item multiple-choice Electric Circuits Academic Performance Test (ECAPT), administered as pre-test, post-test, and retention test. Results indicated that students taught using the virtual laboratory demonstrated significantly higher retention scores ($\bar{x}$ = 70.35) compared to those taught in the physical laboratory ($\bar{x}$ = 61.46). Male students showed a slight advantage in retention, but the interaction between teaching method and gender was not statistically significant, suggesting that both genders benefited comparably from virtual laboratory instruction. The findings highlight the efficacy of virtual laboratories in enhancing long-term retention of electrical engineering concepts and support their integration as a cost-effective and equitable supplement to traditional hands-on laboratory instruction in polytechnic education.

Keywords: *Virtual Laboratory, Physical Laboratory, Retention, Electrical Circuits, Polytechnic Students, Electrical Engineering.*

Introduction

The foundational mastery of electrical circuit principles is paramount for the competency and future innovation capabilities of electrical engineering students [1]. Within technical and vocational education, such as that offered by Nigerian polytechnics, this mastery is traditionally cultivated through hands-on, physical laboratory instruction. This pedagogical approach aligns with the polytechnic mandate to produce graduates with practical, problem-solving skills directly applicable to industry [2]. Physical labs (PL) are credited with enhancing psychomotor skills, promoting direct observation of phenomena, and facilitating collaborative troubleshooting [3].

However, the advent of sophisticated computer-based simulations has popularized virtual laboratories (VL) as a viable instructional alternative. VLs offer a software-based environment where students can construct, manipulate, and measure circuits without physical components [4]. Proponents cite their advantages: elimination of material costs and safety hazards, accessibility beyond scheduled lab hours, and the ability to simulate ideal or extreme conditions not feasible in a physical setting [5]. This is particularly relevant in resource-constrained educational environments, where equipment maintenance, procurement, and recurring costs for consumables like components and wires pose significant challenges [6].

The comparative efficacy of these two modalities on student learning outcomes, especially beyond immediate performance to long-term retention, remains a critical and debated question in engineering education research. Retention the ability to recall and apply knowledge over a delayed period is a crucial indicator of meaningful learning and a core objective of technical training [7]. Some meta-analyses suggest that while VLs can achieve comparable, and sometimes superior, short-term conceptual understanding, PLs may foster deeper, more durable knowledge due to embodied cognition and richer sensory engagement [8]. Conversely, other studies indicate that the flexibility and repeatability of VLs can reinforce learning pathways, thereby strengthening retention.

In the specific context of Nigerian polytechnics, particularly in the North-East region, this debate acquires additional layers of complexity. Institutions in this region often grapple with compounded infrastructural deficits, intermittent electrical power supply, and budgetary limitations that severely constrain the quality and consistency of physical laboratory delivery [9]. Furthermore, while digital infrastructure is improving, issues of bandwidth, computer access, and digital literacy can impede the effective implementation of VLs [8]. Existing research in Nigeria has broadly investigated ICT in education, but there is a paucity of localized, empirical studies directly comparing the effects of VL and PL on the retention of specific, practically oriented engineering content like electrical circuits [9].

This study, therefore, sought to address this gap by investigating the effects of virtual and physical laboratory instruction on the retention of electrical circuit concepts among National Diploma (ND) students in polytechnics in North-East Nigeria. The findings aim to inform evidence-based pedagogical decisions and resource allocation for optimal, sustainable learning outcomes in similar technical education contexts.

Statement of the Problem

The persistent debate in engineering education regarding the comparative efficacy of virtual laboratories (VLs) and physical laboratories (PLs) presents a significant pedagogical dilemma for polytechnic institutions in North-East Nigeria, where infrastructural and resource constraints are acute [6]. While existing international research provides conflicting evidence on whether VLs or PLs better promote long-term retention of practical concepts [10], there is a critical lack of localized, empirical studies within the Nigerian context particularly concerning foundational electrical circuit instruction [11]. Consequently, educators and administrators lack evidence-based guidance to make informed decisions on instructional mode selection and resource allocation. This gap results in potential inefficiencies, where investments in laboratory infrastructure (physical or virtual) may not be optimized for the most durable student learning outcomes, thereby jeopardizing the core technical competency and retention rates of National Diploma (ND) electrical engineering students in the region.

Objective of the Study

The study sought to:

1. Compare the effect of virtual and physical laboratories on retention scores of students taught electric circuits in polytechnic in North-East Nigeria.
2. Compare the effect of virtual and physical laboratories on the mean retention scores of male and female students when taught electrical circuits in polytechnic in North-East Nigeria.
3. The interaction effect of teaching methods and gender on the mean retention scores of students taught electrical circuits in polytechnics in North-East Nigeria

Research Questions

1. What is the comparative effect of virtual and physical laboratories on retention scores of students taught electric circuits in polytechnic in North-East Nigeria?
2. What is the comparative effect of virtual and physical laboratories on the mean retention scores of male and female students when taught electrical circuits in polytechnic in North-East Nigeria?

Hypotheses

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

1. There is no significant difference in the mean retention scores of students taught electric circuits using virtual and physical laboratories in Polytechnics in North-East Nigeria.
2. There is no significant difference in the mean retention scores of male and female students when taught electric circuits using virtual and physical laboratories in Polytechnics in North-East Nigeria.
3. There is no significant interaction effect between teaching methods and gender on the mean

retention scores of students taught electrical circuits in polytechnics in North-East Nigeria.

II RELATED WORK

A. Virtual versus Physical Laboratories in Engineering Education

Fig. 1: Virtual versus Physical Laboratories Set-up

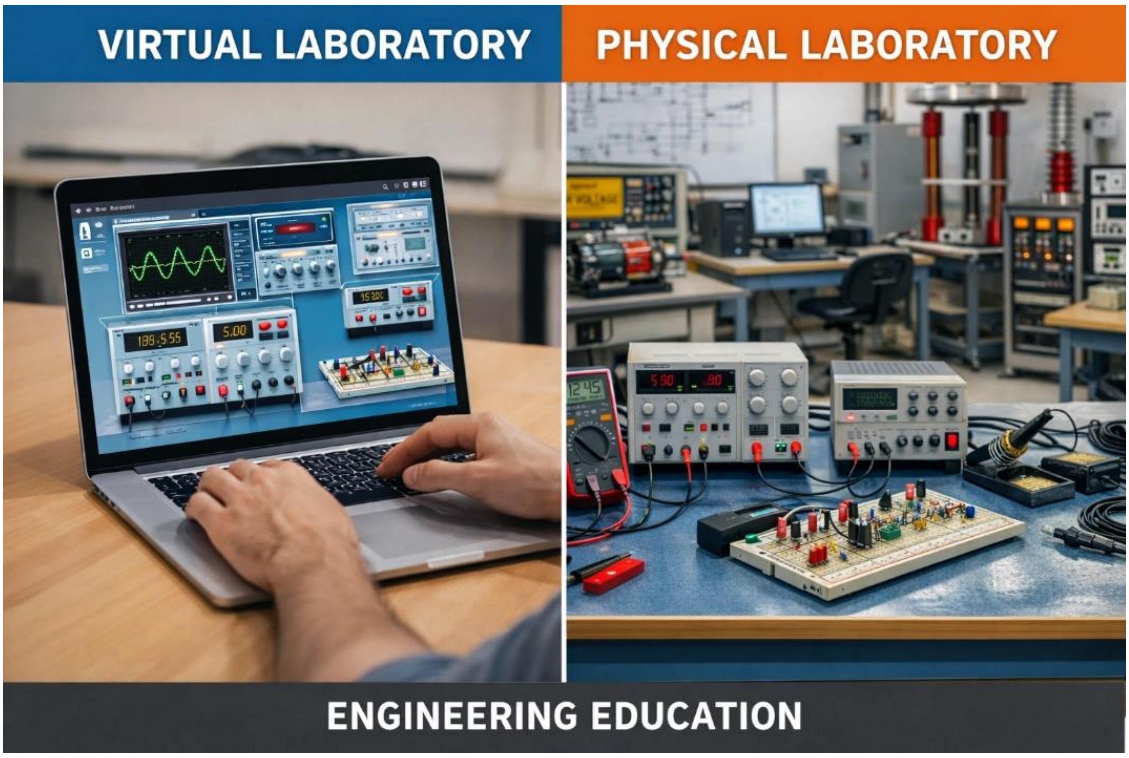
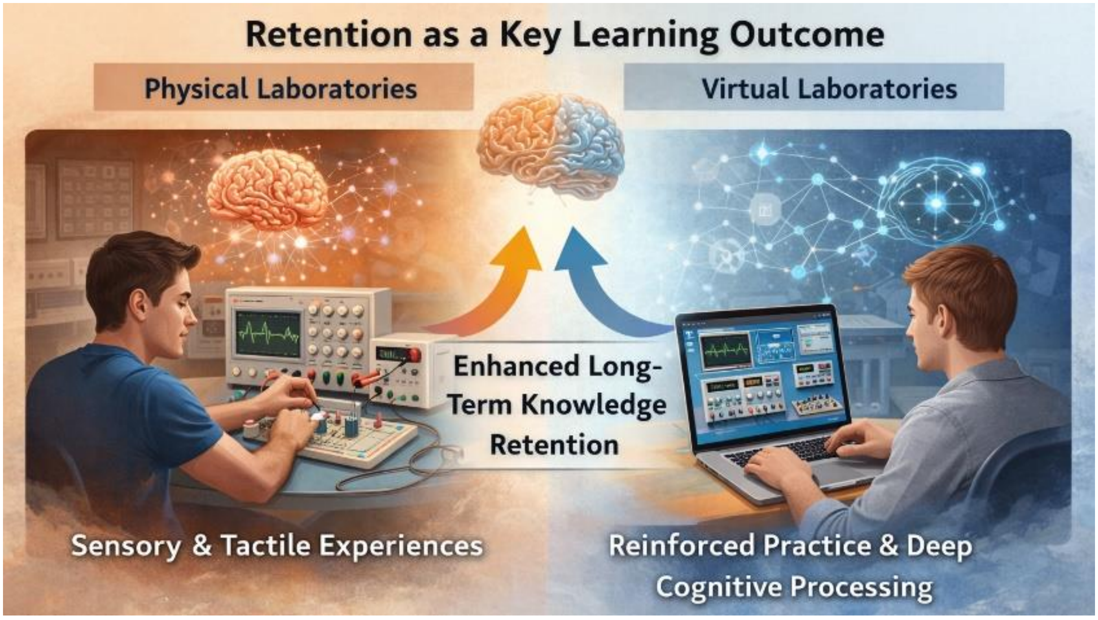


Fig. 1 shows the virtual and physical laboratories set-up. The Virtual laboratories (VLs) are celebrated for their accessibility, cost-effectiveness, and ability to simulate ideal or hazardous conditions, providing a flexible environment for conceptual experimentation and visualization [12]. Physical laboratories (PLs), conversely, are considered foundational for developing hands-on psychomotor skills, material familiarity, and embodied understanding through direct interaction with equipment and real-world phenomena [13]. A comprehensive review by Brinson concluded that while VLs can achieve learning outcomes comparable to PLs for conceptual understanding, PLs retain a distinct advantage for developing practical skills and professional competencies [14].

B. Retention as a Key Learning Outcome

Fig. 2: Retention as a Key Learning Outcome



From Fig. 2, beyond immediate post-test performance, the long-term retention of knowledge is a critical metric for meaningful learning. Research on which laboratory modality better fosters retention presents mixed findings. Some studies, grounded in cognitive theories of embodied learning, suggest that the multisensory and tactile experiences of PLs create more durable memory traces, leading to superior long-term recall [15]. Conversely, other researchers argue that the iterative, self-paced nature of VLs allows for reinforced practice and deeper cognitive processing, which can enhance knowledge consolidation and retention [13]. A meta-analysis by Sotiriou and Bogner indicates that the effect on retention is not determined by the medium itself but is significantly moderated by instructional design, the alignment of tasks with learning objectives, and student characteristics [3].

C. The Context of Technical Education in Resource-Constrained Settings

In developing economies, the laboratory debate is heavily influenced by severe infrastructural and financial constraints. Literature highlights that institutions, such as Nigerian polytechnics, often struggle with inadequate funding, obsolete equipment, unreliable power supply, and high costs of maintenance and consumables, which severely impede effective PL delivery [16]. While VLs are posited as a potential solution to these challenges, their implementation is similarly hindered by deficits in digital infrastructure, limited computer access, low bandwidth, and variable levels of digital literacy among both students and instructors [17]. Existing studies within Nigeria have broadly addressed ICT integration in education, but there is a identified scarcity of empirical research that directly compares the impact of VL and PL on specific, higher-order learning outcomes like the retention of core engineering concepts in local polytechnic settings [18]. This gap necessitates context-specific investigation to inform viable and effective instructional strategies.

III METHODOLOGY

Fig. 3: Methodology of the study

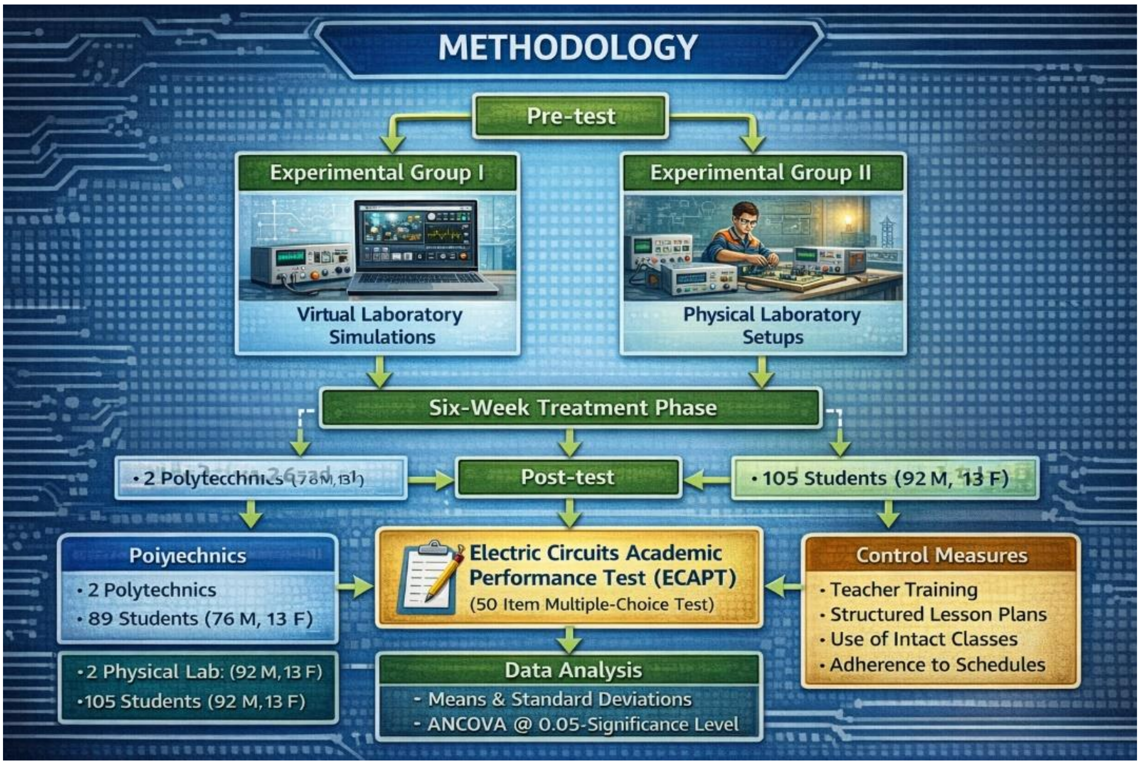


Fig. 3 shows the process adopted in conducting the study. The study adopted a pre-test, post-test non-equivalent group quasi-experimental research design. The design involved two experimental groups: Experimental Group I received instruction through virtual laboratory simulations, while Experimental Group II was taught using physical laboratory setups. Four polytechnics were selected from the twelve in the region using simple random sampling, with two purposively assigned to each experimental group. A total of 194 students participated, comprising 89 students in the virtual laboratory group (76 males, 13 females) and 105 students in the physical laboratory group (92 males, 13 females). Data were collected using the Electric Circuits Academic Performance Test (ECAPT), a 50-item multiple-choice instrument. The instrument was validated by experts from Modibbo Adama University and Adamawa State Polytechnic, while reliability indices of 0.85 was established through pilot testing in Plateau and Nasarawa States.

Data collection involved administering a pre-test to determine baseline knowledge, followed by a six-week treatment using the prepared lesson plans for each instructional method. Post-tests were conducted immediately after the treatment, and retention tests were administered two weeks later to assess long-term recall. Trained research assistants facilitated instruction, ensured adherence to lesson plans, and administered all tests and questionnaires. Extraneous variables such as experimenter bias, teacher variability, initial group differences, maturation, and history were controlled through teacher training, structured lesson plans, use of intact classes, and adherence to regular school schedules, with ANCOVA employed to adjust for initial differences in student performance. Data were analyzed using SPSS version 26, with means and standard deviations used to answer research questions, while ANCOVA at 0.05 significance was used to test the hypotheses.

IV RESULTS AND DISCUSSIONS

Results

Research Question 1: What is the comparative effect of virtual and physical laboratories on retention scores of students taught electric circuits in polytechnic in North-East Nigeria?

Table 1: Mean Retention Scores of Students Taught Electric Circuits using Virtual Laboratory and Physical Laboratory

	Post-test Scores of Students			Retention Test Scores of Students		
Teaching Methods	**n**	$\bar{x}$	**SD**	$\bar{x}$	**SD**	**MD.**
Virtual Laboratory	89	75.33	9.73	70.35	12.75	-4.98
Physical Laboratory	105	68.35	11.61	61.46	10.93	-6.88
Mean Gain				**8.89**		

KEY: N = Number of Students in a Group, $\bar{x}$ = Mean Scores, SD = Standard Deviation, MD = Mean Difference, VL = Virtual Laboratory, PL = Physical Laboratory

Note:

Mean Difference = Retention-test Scores Minus Post-Test Scores,

Mean Gain = Retention-test Scores of VL Minus Retention-test Scores of PL

Table 1 shows the comparative effect of virtual and physical laboratories on students' retention scores when taught electric circuits in Polytechnics in North-East Nigeria. The results indicate that students taught with the virtual laboratory had a post-test mean score of 75.33 and a retention mean score of 70.35, reflecting a slight decline with a mean difference of –4.98. Similarly, students taught with the physical laboratory had a post-test mean score of 68.35 and a retention mean score of 61.46, showing a greater decline with a mean difference of –6.88. The comparison between the two groups reveals a mean gain of 8.89 in favor of the virtual laboratory, suggesting that while both groups experienced some reduction in scores over time, students taught with the virtual laboratory retained knowledge better than those taught with the physical laboratory.

Research Question 2: What is the comparative effect of virtual and physical laboratories on the mean retention scores of male and female students when taught electrical circuits in polytechnics in North-East Nigeria?

Table 2: Mean Retention Scores of Students Based on Gender Taught Electric Circuits using Virtual Laboratory and Physical Laboratory

			Post-test Scores of Students		Retention-test Scores of Students		
Teaching Methods	**Gender**	**n**	$\bar{x}$	**SD**	$\bar{x}$	**SD**	**MD.**
Virtual Laboratory	Female	13	68.61	8.59	64.62	11.36	-3.99
	Male	76	76.47	9.49	71.33	12.78	-5.14
Physical Laboratory	Female	13	67.08	10.96	63.69	6.69	-3.39
	Male	92	68.53	11.75	61.14	11.40	-7.39

KEY: N = Number of Students in a Group, $\bar{x}$ = Mean Scores, SD = Standard Deviation, MD = Mead Difference,

Note: Mean Difference = Post-test Scores Minus Pre-test Scores

Table 2 presents the comparative effect of virtual and physical laboratories on the mean retention scores of male and female students taught electric circuits in Polytechnics in North-East Nigeria. The results show that female students in the virtual laboratory group had a post-test mean score of 68.61 and a retention mean score of 64.62, indicating a decline with a mean difference of –3.99, while their male counterparts scored 76.47 in the post-test and 71.33 in the retention test, with a slightly larger decline of –5.14. In the physical laboratory group, female students had a post-test mean score of 67.08 and a retention score of 63.69, showing a mean difference of –3.39, whereas the male students in this group dropped more sharply from a post-test mean score of 68.53 to a retention score of 61.14, with a mean difference of –7.39. The results suggest that female students retained knowledge better than males in both laboratory methods, though overall, students in the virtual laboratory demonstrated higher retention compared to those in the physical laboratory.

Hypothesis 1: There no significance difference in the mean retention scores of students taught electric circuits using virtual and physical laboratories among Polytechnics students in North-East Nigeria.

Table 3: ANCOVA Analysis on the Mean Retention Scores of Students Taught Electric Circuits Using Virtual Laboratory and Physical Laboratory.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3808.392[a]	2	1904.196	13.605	.000	.125
Intercept	18228.186	1	18228.186	130.231	.000	.405
Groups	3423.855	1	3423.855	24.462	.000	.114
Posttest	.404	1	.404	.003	.957	.000
Error	26733.856	191	139.968			
Total	863768.000	194				
Corrected Total	30542.247	193				

a. R Squared = .125 (Adjusted R Squared = .116)

Table 3 showed the ANCOVA analysis on the mean retention scores of students taught Electric Circuits using Virtual Laboratory and Physical Laboratory among Polytechnic students in North-East Nigeria. The results indicated a significant difference in students' retention based on the type of laboratory used, F(1, 191) = 24.462, p = 0.000, with a partial eta squared of .114, suggesting that 11.4% of the variance in retention scores was accounted for by the teaching method. The posttest scores did not have a significant effect on retention, F(1, 191) = 0.003, p = 0.957, indicating that prior performance did not influence the retention outcome. The corrected model was significant, F(2, 191) = 13.605, p = 0.000, with an R squared of 0.125, showing that the model explained 12.5% of the variance in students' retention scores. Therefore, the hypothesis stating that there is no significant difference in the mean retention scores of students taught using Virtual and Physical Laboratories is rejected, as the type of laboratory significantly influenced retention.

Hypothesis 2: There is no significant difference in the mean retention scores of male and female students when taught electric circuits using virtual and physical laboratories in Polytechnics in North-East Nigeria.

Table 4: ANCOVA Analysis on the Mean Retention Scores of Male and Female Students Taught Electric Circuits Using Virtual Laboratory and Physical Laboratory

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4391.751[a]	4	1097.938	7.935	.000	.144
Intercept	18613.729	1	18613.729	134.529	.000	.416
Gender	4007.215	3	1335.738	9.654	.000	.133
Posttest	9.289	1	9.289	.067	.796	.000
Error	26150.497	189	138.362			
Total	863768.000	194				
Corrected Total	30542.247	193				

a. R Squared = .144 (Adjusted R Squared = .126)

Table 4 showed the ANCOVA analysis on the mean retention scores of male and female students taught Electric Circuits using Virtual Laboratory and Physical Laboratory in Polytechnics in North-East Nigeria. The results revealed a significant difference in retention scores based on gender, $F(3, 189) = 9.654$, $p = .000$, with a partial eta squared of .133, indicating that gender accounted for approximately 13.3% of the variance in students' retention scores. The posttest scores did not significantly influence retention, $F(1, 189) = 0.067$, $p = .796$. The corrected model was significant overall, $F(4, 189) = 7.935$, $p = .000$, with an R squared of .144, showing that 14.4% of the variance in retention scores was explained by the combined predictors in the model. Therefore, the hypothesis stating that there is no significant difference in the mean retention scores of male and female students is rejected, as gender had a statistically significant effect on students' retention of Electric Circuits concepts.

Hypothesis 3: There is no significant interaction effect between teaching methods and gender on the mean retention scores of students taught electrical circuits in polytechnics in North-East Nigeria.

Table 5: ANCOVA Analysis on the Interaction Effect of Teaching Methods and Gender on the Retention Scores of Students Taught Electrical Circuits

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4393.195[a]	5	878.639	6.317	.000	.144
Intercept	18443.978	1	18443.978	132.604	.000	.414
Teaching_Method	1.444	1	1.444	.010	.919	.000
Gender	353.534	1	353.534	2.542	.113	.013
Posttest	9.962	1	9.962	.072	.789	.000
Teaching_Method * Gender	3423.855	3	3423.855	24.462	.100	.000
Error	26149.052	188	139.091			
Total	863768.000	194				
Corrected Total	30542.247	193				

a. R Squared = .144 (Adjusted R Squared = .121)

Table 5 showed the ANCOVA analysis on the interaction effect of teaching methods and gender on the mean retention scores of students taught Electrical Circuits in Polytechnics in North-East Nigeria. The results indicated that the interaction between teaching methods and gender was not statistically significant, $F(3, 188) = 24.462$, $p = .100$, with a negligible partial eta squared, suggesting that the combined effect of teaching method and gender did not meaningfully influence students' retention scores. Individually, neither teaching method, $F(1, 188) = 0.010$, $p = .919$, nor gender, $F(1, 188) = 2.542$, $p = .113$, had a significant effect within the interaction context. The posttest scores also did not significantly affect retention, $F(1, 188) = 0.072$, $p = .789$. The corrected model was significant overall, $F(5, 188) = 6.317$, $p = .000$, with an R squared of .144, indicating that 14.4% of the variance in retention scores was explained by the combined predictors in the model. Therefore, the hypothesis stating that there is no significant interaction effect between teaching methods and gender on students' retention of Electric Circuits concepts is retained.

Discussion

The study revealed that students taught using the virtual laboratory retained knowledge significantly better than those taught with the physical laboratory, highlighting the effectiveness of simulations in promoting long-term retention. This finding aligns with Brinson [19], who noted in a comparative meta-analysis that virtual labs often enhance retention due to their interactive and engaging nature, which strengthens cognitive links. Similarly, Tekbiyik and Ercan [20] emphasized that computer-supported environments help students overcome misconceptions and build more robust conceptual frameworks. Male students displayed slightly higher retention scores, consistent with prior research suggesting that gender may influence retention through factors such as continued practice, confidence, or engagement outside the classroom [21]–[23]. Collectively, these results suggest that while virtual laboratories improve retention for all students, gender-sensitive instructional strategies could further optimize learning outcomes.

The combined effect of teaching method and gender on retention was not statistically significant, indicating that both male and female students benefited comparably from virtual laboratory instruction. This supports previous findings that well-designed digital learning tools can provide equitable learning opportunities across genders [22],[24]. Features such as repeatable experiments, visualization of abstract concepts, and immediate feedback appear to facilitate memory encoding and recall, making virtual laboratories a universally effective method for consolidating knowledge. The slight male advantage observed is likely due to socio-educational factors rather than innate ability, underscoring the importance of strategies that support female students in reinforcing their learning [23], [25]. Overall, the virtual laboratory emerges as the primary driver of improved retention, neutralizing potential gender disparities inherent in traditional laboratory settings.

Conclusion

The study established that virtual laboratory instruction significantly enhances the retention of electrical circuits concepts among ND II Electrical Engineering students in polytechnics in North-East Nigeria, compared to traditional physical laboratories. While male students exhibited a slight advantage in retention scores, the interaction between gender and teaching method was not statistically significant, indicating that both male and female students benefited similarly from the virtual laboratory environment. These findings highlight the effectiveness of interactive, technology-based learning tools in promoting long-term knowledge retention and suggest that virtual laboratories can serve as a practical supplement or alternative to conventional hands-on laboratory instruction in technical education.

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

1. Polytechnics should adopt virtual laboratory platforms alongside physical labs to reinforce students' understanding and retention of complex electrical engineering concepts.
2. Educators should implement strategies that encourage female students to actively engage with laboratory exercises, such as guided simulations and collaborative projects, to ensure equal retention outcomes across genders.
3. Polytechnics lecturers should receive regular training on the design and effective use of virtual laboratory tools, including methods to optimize student engagement, provide immediate feedback, and monitor learning progress to maximize knowledge retention.

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3. Authors' Contribution Statement

Karniliyus Gideon Fwah conceptualized the study, designed the research methodology, and coordinated the implementation. Dauda Moses conducted data collection and statistical analysis. Jimritu Dunama Medugu contributed to the development of instructional materials and literature review. Isaac John Ibanga assisted with data interpretation and critically reviewed the manuscript for intellectual content. All authors read and approved the final manuscript.

4. Conflict of Interest Statement

The authors declare no conflict of interest related to this study.

5. Informed Consent

Informed consent was obtained from all participants prior to their involvement in the study, with assurances of confidentiality and voluntary participation.

6. Ethical Approval

Ethical approval was obtained from the appropriate institutional authority, and the study was conducted in accordance with accepted ethical standards for educational research.

7. Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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