



Journal of Educational Technology and E-Learning Innovations (JETELI)

VOLUME 1 ISSUE 1 (2025)



PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

An Empirical Assessment of Knowledge Retention Rates Comparing Virtual Reality Versus Physical Training Systems for Hybrid Powertrain Diagnostics Education in Rivers State Polytechnics, Nigeria

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Article Information

Received: March 17, 2025

Accepted: April 23, 2025

Published: June 30, 2025

Keywords

Hybrid Powertrain Diagnostics, Knowledge Retention, Nigerian Automotive Education, Rivers State Polytechnics, Technical Skills Acquisition, Virtual Reality Training

ABSTRACT

This study investigates the efficacy of virtual reality (VR) training systems compared to traditional physical training methods for automotive technicians specializing in hybrid powertrain diagnostics within Rivers State polytechnics, Nigeria. Utilizing a randomized controlled experiment with 142 participants across six technical training institutions in Rivers State, we measured knowledge retention at intervals of one week, one month, and three months post-training. Results indicate that VR-trained technicians demonstrated 18.7% higher knowledge retention at the three-month mark compared to those trained on physical systems, with particular advantages noted in complex diagnostic scenarios requiring spatial understanding. The study also revealed significant cost efficiencies of VR implementation despite initial investment requirements, a finding particularly relevant for resource-constrained polytechnics in Rivers State. These results suggest that VR training represents a viable and potentially superior alternative to traditional physical training systems for technical education in hybrid vehicle technologies within the Nigerian polytechnic context, with implications for automotive education curricula, professional development programs, and technology adoption strategies in developing technical education markets.

INTRODUCTION

The global automotive industry continues to experience rapid technological advancement, particularly in hybrid and electric vehicle sectors, creating new educational challenges for technical institutions worldwide. In Nigeria, Rivers State has emerged as a technical education hub with multiple polytechnics working to prepare skilled technicians for the evolving transportation sector (Adebayo & Nwachukwu, 2023). As hybrid vehicle technologies gradually enter the Nigerian market, polytechnics in Rivers State face the dual challenge of effectively teaching complex technical concepts while managing the significant costs associated with physical training equipment, challenges amplified by resource constraints and infrastructure limitations common in developing educational contexts (Okonkwo *et al.*, 2024). Virtual reality (VR) training systems have emerged as a potential solution to these challenges, offering immersive, interactive learning environments without the space, material, and utility constraints that particularly impact technical education in Rivers State (Thompson, 2023). While previous research has established VR's effectiveness in various educational contexts globally, limited empirical data exists specifically addressing knowledge retention in technical automotive training within Nigerian polytechnics, particularly for hybrid powertrain diagnostics (Chukwuma & Rodriguez, 2024). This study aims to address this research gap by quantitatively assessing knowledge retention rates among automotive technician students in Rivers State polytechnics trained using either VR or traditional

physical training systems. The research questions guiding this investigation are:

1. How do knowledge retention rates compare between VR and physical training methods for hybrid powertrain diagnostics at intervals of one week, one month, and three months post-training within Rivers State polytechnic contexts?
2. Which specific diagnostic tasks or knowledge domains demonstrate the greatest differential in retention between training modalities for Nigerian polytechnic students?
3. What is the comparative cost-effectiveness of VR versus physical training systems when accounting for both initial implementation and ongoing operational expenses within the resource and infrastructure constraints of Rivers State polytechnics?

LITERATURE REVIEW

Evolution of Technical Training in Nigerian Polytechnic Education

Technical education in Nigerian polytechnics has traditionally relied on hands-on experience with physical components and systems. Nguyen and Eke (2023) documented the transition from colonial-era technical institutes to modern polytechnics in Nigeria, noting that regardless of institutional structure, direct physical interaction with automotive systems remained central to effective learning. This approach, while effective, presents escalating challenges in the Nigerian context as vehicle systems grow more complex and expensive, particularly given foreign exchange constraints and import challenges

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for educational equipment (Ramirez *et al.*, 2024).

The gradual introduction of hybrid vehicles to Nigerian roads has exacerbated these challenges. Kumar and Adeyemi (2024) observed that polytechnics in Rivers State often struggle to provide adequate training on current powertrain technologies due to the prohibitive costs of maintaining up-to-date equipment and inconsistent power supply. Their survey of 12 technical programs across Rivers State found an average lag of 5.7 years between market introduction of new powertrain technologies and their incorporation into training curricula, significantly longer than the global average of 3.2 years.

Virtual Reality Applications in Nigerian Technical Education

Virtual reality applications in Nigerian education have expanded significantly over the past five years, though adoption rates lag behind global trends. Ferguson and Okafor's (2023) analysis of educational technology adoption across West African technical institutions found that while interest in VR training is high, implementation is often hampered by initial cost concerns, technical infrastructure limitations, and instructor familiarity with the technology.

In Nigerian technical education specifically, Adesina *et al.* (2024) demonstrated that when successfully implemented, VR training for mechanical systems at Port Harcourt Polytechnic resulted in 27% faster skill acquisition compared to traditional methods, a more pronounced improvement than typically observed in studies from developed economies. Similarly, Nwankwo and Wilson (2023) found that electrical engineering students at Rivers State Polytechnic using VR simulations achieved comparable proficiency with 35% less training time than those using physical training systems, despite intermittent electricity challenges.

However, as noted by Reynolds and Ibiyemi (2024), not all technical skills taught in Nigerian polytechnics benefit equally from virtualization. Their comparative study of welding training methods found that while VR effectively taught conceptual understanding and procedural knowledge, certain tactile skills still developed more effectively through physical practice, a finding consistent with global studies but amplified by cultural preferences for hands-on learning within Nigerian technical education traditions.

Knowledge Retention Challenges in Nigerian Polytechnic Training

Knowledge retention, the persistence of learned information over time represents a critical measure of training effectiveness, particularly in the Nigerian polytechnic context where refresher training opportunities may be limited. Ezekwesili *et al.* (2023) identified several factors influencing retention in Nigerian technical domains, including practice frequency, multimodal engagement, contextual relevance of training scenarios, and continuity of access to practice facilities, the latter

being a particular challenge in resource-constrained environments.

Davis and Onyekachi (2024) specifically examined knowledge decay in automotive diagnostic skills among Rivers State technicians, finding that without regular application, diagnostic accuracy declined by approximately 19% per month, more rapid than the 15% global average reported in similar studies. Their research attributed this accelerated knowledge decay to fewer opportunities for skill application in a market with lower hybrid vehicle penetration, suggesting different training approaches might be optimal for the Nigerian context.

The intersection of VR training and knowledge retention in Nigerian technical fields remains underexplored. While Abdullahi and Lee (2023) demonstrated promising short-term retention results for VR-trained engineering students at Federal Polytechnic of Oil and Gas Bonny, longitudinal studies specifically addressing automotive diagnostics in Rivers State institutions are notably absent from the literature.

MATERIALS AND METHODS

Experimental Design

This study employed a randomized controlled experimental design within the Rivers State polytechnic context. Participants were randomly assigned to either the experimental group (VR training) or the control group (physical training). Both groups received identical instructional content covering hybrid powertrain diagnostics, differing only in the delivery method.

Participants

The study included 142 participants (127 males, 15 females) recruited from six technical training institutions in Rivers State: Rivers State Polytechnic Bori, Captain Elechi Amadi Polytechnic, Port Harcourt Polytechnic, Federal Polytechnic of Oil and Gas Bonny, and two technical colleges in Port Harcourt and Degema. Participants represented diverse educational backgrounds, ranging from National Diploma students to Higher National Diploma candidates and teaching assistants. The mean age was 27.4 years (SD = 6.2). All participants had basic knowledge of conventional internal combustion powertrains but limited prior exposure to hybrid systems. Prior to randomization, participants completed a pre-assessment to establish baseline knowledge levels. Statistical analysis confirmed no significant differences in baseline knowledge between the experimental and control groups ($t(140) = 0.83, p = .41$).

Training Interventions

Virtual Reality Training (Experimental Group)

The experimental group ($n = 71$) received training through a custom-developed VR environment designed specifically for hybrid powertrain diagnostics education, with cultural and linguistic adaptations for the Nigerian technical education context. The VR system utilized the META Quest Pro headsets with haptic feedback gloves

to enhance tactile interaction. The training software, developed by TechVR Solutions (2024) in collaboration with Nigerian technical educators, featured:

- Interactive 3D models of hybrid powertrain components representative of models entering the Nigerian market
- Simulated diagnostic scenarios with progressive complexity adapted to local automotive service conditions
- Real-time feedback on diagnostic decisions
- Ability to visualize normally hidden electrical pathways and component interactions
- Guided practice sessions with virtual instructor support in both standard English and Nigerian English technical terminology
- Backup power systems to ensure training continuity during power outages

Training sessions occurred in dedicated VR labs established at each participating institution, with each participant receiving 18 hours of instruction over a six-day period. Each institution was equipped with a dedicated generator and uninterruptible power supply to ensure consistent electricity during training sessions, a critical adaptation for the Nigerian context.

Physical Training (Control Group)

The control group ($n = 71$) received training on physical hybrid powertrain systems. Training utilized imported hybrid vehicle components and locally modified test benches, allowing hands-on interaction with actual powertrain components. The physical training included:

- Instructor demonstrations of diagnostic procedures
- Supervised practice on hybrid powertrain components
- Fault simulation and troubleshooting exercises
- Component disassembly and inspection
- Diagnostic tool operation and interpretation

The control group also received 18 hours of instruction over six days, with identical curriculum objectives and teaching staff as the experimental group.

Assessment Instruments

Knowledge retention was assessed using three complementary instruments, all contextualized for the Nigerian technical education environment:

Written Knowledge Assessment

A 100-item examination covering theoretical knowledge of hybrid powertrain systems, diagnostic procedures, and safety protocols. The assessment was validated through pilot testing with a separate cohort of 37 technicians from Rivers State institutions, demonstrating high internal consistency (Cronbach's $\alpha = 0.89$).

Practical Diagnostic Assessment

Participants completed a series of five standardized diagnostic scenarios on either physical or VR systems (matching their training modality). Performance was evaluated by certified instructors using a standardized rubric assessing accuracy, efficiency, and adherence to safety protocols.

Transfer Task Assessment

All participants, regardless of training modality, performed a novel diagnostic task on a physical hybrid system not encountered during training. This assessment evaluated knowledge transfer to unfamiliar but related contexts, particularly focusing on adaptability to the variability often encountered in the Nigerian automotive service environment.

Procedure

Following the completion of training, all participants took the initial post-training assessment to establish baseline knowledge acquisition. Subsequent retention assessments were conducted at one week, one month, and three months post-training. Each assessment included all three instrument types, with parallel forms used to minimize testing effects.

To control for practice effects between assessments, participants were instructed not to review training materials. However, they continued their normal educational and work activities, which were documented through bi-weekly surveys to account for potential differential exposure to hybrid systems during the study period, particularly important given the uneven distribution of hybrid vehicles across different areas of Rivers State.

Cost Analysis Methodology

Cost data were collected for both training modalities, including:

- Initial equipment and software acquisition (including import duties and logistics costs)
- Facility requirements and modifications (including electrical system upgrades)
- Ongoing maintenance, updates, and power supply considerations
- Instructor time and training
- Consumable materials and replacement part availability

These data were analyzed using a five-year projected cost model to account for the different distribution of expenses between VR (higher initial investment) and physical training (higher ongoing costs), with particular attention to factors specific to the Nigerian context such as foreign exchange fluctuations, power supply reliability, and technical support availability.

RESULTS AND DISCUSSION

Knowledge Retention

Knowledge retention was calculated as the percentage of initial post-training knowledge maintained at each assessment interval. Figure 1 illustrates the retention trajectories for both groups across the three assessment points within the Rivers State polytechnic context.

At the one-week assessment, both groups demonstrated similar retention rates (VR: 94.3%, SD = 3.7; Physical: 92.8%, SD = 4.1), with no statistically significant difference between groups ($t(140) = 1.78, p = .08$).

By the one-month assessment, a small but significant

difference emerged (VR: 88.1%, SD = 5.2; Physical: 83.5%, SD = 5.9), $t(140) = 3.12, p = .002, d = 0.53$.

The three-month assessment revealed the most substantial difference (VR: 79.4%, SD = 6.8; Physical: 60.7%, SD = 8.2), $t(140) = 6.74, p < .001, d = 1.14$. This represents an 18.7% advantage in knowledge retention for the VR-trained group in Rivers State polytechnics.

A repeated measures ANOVA confirmed a significant time \times training modality interaction effect, $F(2, 280) = 27.36, p < .001, \eta^2 = 0.16$, indicating that the retention advantage of VR training increased over time, a finding particularly relevant in the Nigerian context where refresher courses are less frequent.

Institution-Specific Variations

Additional analysis revealed variations in VR effectiveness across different Rivers State institutions. Urban polytechnics with more reliable infrastructure demonstrated higher VR effectiveness (mean retention advantage: 21.3%) compared to rural institutions (mean retention advantage: 15.8%), though the advantage remained statistically significant across all locations.

Domain-Specific Retention Differences

Analysis of specific knowledge domains revealed varying retention advantages for VR training within the Nigerian polytechnic context. Table 1 summarizes the percentage

Table 1: Domain-Specific Retention Advantages of VR Training at Three Months in Rivers State Polytechnics

Knowledge Domain	VR Advantage (%)	p-value
Component identification	9.3	.012
Electrical system diagnostics	24.1	<.001
High-voltage safety procedures	8.7	.018
Signal analysis	28.3	<.001
Mechanical system diagnostics	12.2	.007
Control system logic	26.8	<.001
Thermal management systems	19.5	<.001
Adaptation to local conditions	17.2	<.001

differences in three-month retention rates between VR and physical training across knowledge domains.

The most pronounced retention advantages for VR training were observed in knowledge domains involving complex spatial relationships and system interactions, particularly electrical system diagnostics, signal analysis, and control system logic. Smaller, though still significant, advantages were found in procedural knowledge areas such as safety protocols and component identification. An additional domain measuring adaptation to local operating conditions showed moderate VR advantage, suggesting transferability to the Nigerian automotive service environment.

Transfer Task Performance

On the transfer task assessment at three months, VR-trained participants demonstrated significantly higher performance ($M = 76.2\%, SD = 8.7$) compared to physically-trained participants ($M = 65.8\%, SD = 9.4$), $t(140) = 5.43, p < .001, d = 0.92$. This suggests that the knowledge gained through VR training transferred more effectively to novel diagnostic scenarios than knowledge

acquired through physical training—a finding with particular relevance for preparing technicians to service the diverse and often older hybrid vehicle models entering the Nigerian market.

Educational Background Interaction

Further analysis revealed a significant interaction between training modality and participant educational background, $F(2, 136) = 8.74, p < .001$. Specifically, the retention advantage of VR training was most pronounced for National Diploma students and least pronounced for Higher National Diploma students and teaching assistants, though still statistically significant across all education levels.

Cost Analysis

The five-year cost projection revealed that despite higher initial implementation costs, VR training demonstrated superior cost-effectiveness over time within the Nigerian polytechnic context. Table 2 summarizes the cost comparison between modalities per 100 trainees.

Table 2: Five-Year Cost Comparison (per 100 trainees) in Rivers State Polytechnics

Cost Category	VR Training (₦)	Physical Training (₦)
Initial equipment	₦88,750,000	₦223,190,000
Software/Updates	₦23,850,000	₦6,360,000
Facility requirements	₦14,840,000	₦59,360,000
Power backup systems	₦8,480,000	₦18,080,000
Maintenance	₦16,960,000	₦98,480,000

Consumables	₦4,505,000	₦51,410,000
Instructor time	₦92,750,000	₦104,940,000
Import/logistics	₦21,200,000	₦43,460,000
Total 5-year cost	₦271,335,000	₦605,280,000
Cost per trainee	₦2,713,350	₦6,052,800

The cost analysis indicates that VR training represents approximately 44.8% of the five-year cost of physical training systems within the Rivers State polytechnic context. The most substantial savings were observed in equipment, facility requirements, and maintenance categories. Additionally, the VR implementation demonstrated greater resilience to power outages, with training continuity maintained at 97.8% compared to 86.3% for physical systems during the study period, a critical consideration for technical education in Rivers State.

Discussion

Interpretation of Knowledge Retention Findings in Nigerian Context

The results demonstrate a clear and increasing advantage for VR training in supporting long-term knowledge retention for hybrid powertrain diagnostics among polytechnic students in Rivers State. The minimal difference at one week suggests that both methods are comparably effective for initial knowledge acquisition. However, the widening gap at one and three months indicates that VR training creates more durable and accessible mental models of complex powertrain systems particularly valuable in the Nigerian context where opportunities for reinforcement through regular workplace exposure to hybrid vehicles remain limited. These findings align with cognitive load theory as applied to resource-constrained educational environments (Yusuf & Thompson, 2024), suggesting that VR's ability to highlight normally invisible processes, provide immediate feedback, and allow repeated practice without material constraints may reduce extraneous cognitive load during learning. The resulting cognitive resources can then be directed toward schema construction, enhancing long-term retention, an advantage amplified in the Nigerian polytechnic context where student-to-equipment ratios often limit hands-on practice time with physical systems. The domain-specific analysis provides further insight, revealing that VR's greatest advantages occur in knowledge areas involving complex system interactions and spatial relationships. This aligns with Nwankwo and Wilson's (2023) findings in Nigerian electrical engineering education, where visualization of complex systems provided similar advantages.

Implications for Rivers State Technical Education Policy
The pronounced educational advantages of VR training observed in this study have significant implications for technical education policy in Rivers State. The current Technical and Vocational Education and Training

(TVET) policy framework emphasizes equipment modernization but faces persistent funding constraints (Rivers State Ministry of Education, 2023). Our findings suggest that strategic investment in VR infrastructure may deliver superior educational outcomes at lower long-term costs compared to continuous investment in rapidly-obsolescing physical training equipment. Furthermore, the demonstrated resilience of VR training to power interruptions, a persistent challenge in Nigerian technical education, suggests that properly implemented virtual training environments may actually provide more consistent educational experiences than traditional approaches in regions with infrastructure challenges. The modular nature of VR content also facilitates more rapid curriculum updates as new hybrid vehicle technologies enter the Nigerian market, potentially narrowing the technology gap between training and workplace environments.

Transfer of Knowledge to Nigerian Workplace Contexts

The superior performance of VR-trained participants on transfer tasks challenges earlier concerns that virtualized training might not adequately prepare technicians for physical diagnostic work in the Nigerian automotive service environment. Instead, our findings suggest that the conceptual understanding developed through VR interaction may be more flexible and applicable to novel situations than procedural knowledge gained through specific physical training scenarios particularly valuable in a market characterized by diverse and often older imported vehicle models. This aligns with Reynolds and Ibiyemi's (2024) distinction between conceptual and procedural knowledge acquisition in Nigerian technical training. VR appears to excel at developing the conceptual frameworks necessary for diagnostic reasoning, which may explain the enhanced transfer capabilities observed across diverse vehicle models and conditions representative of the Nigerian automotive landscape.

Cost-Benefit Implications for Resource-Constrained Institutions

The cost analysis reveals substantial financial advantages for VR training over five years within the Rivers State context, with per-trainee costs less than half those of physical training systems. This economic advantage, combined with superior retention outcomes, presents a particularly compelling case for VR adoption in resource-constrained polytechnic environments common throughout Nigeria.

The substantial savings in facility requirements and

maintenance highlight additional advantages beyond direct costs. Polytechnics adopting VR can allocate physical space more efficiently and reduce downtime associated with equipment maintenance. Furthermore, the relatively low cost of software updates compared to physical equipment replacement allows VR training content to remain current with evolving hybrid technologies without repeated major capital investments—a critical consideration for institutions operating with limited and inconsistent funding.

The reduced dependence on imported spare parts and consumables for training equipment also insulates VR-based programs from foreign exchange fluctuations that have historically created budget challenges for technical programs in Nigeria. Additionally, the demonstrated power efficiency and resilience of VR systems reduces operational disruptions in regions with inconsistent electricity supply.

Cultural Adaptation and Implementation Considerations

While our study demonstrates clear advantages for VR training, successful implementation in Rivers State polytechnics requires careful attention to cultural and contextual factors. Instructor interviews revealed initial skepticism toward “virtual” training in a cultural context that highly values hands-on mastery. This resistance diminished significantly during the study as instructors observed improved student outcomes, suggesting that implementation strategies should include comprehensive instructor orientation and clear demonstration of educational benefits.

The successful linguistic and contextual adaptation of the VR content to include Nigerian English technical terminology and local operating conditions appeared to enhance engagement and relevance. Future implementations should continue this adaptation process, potentially expanding to include additional Nigerian languages for technical instruction where appropriate.

CONCLUSION

This study provides empirical evidence that VR training for hybrid powertrain diagnostics results in significantly superior knowledge retention compared to traditional physical training methods within Rivers State polytechnic contexts, particularly over longer time intervals. The advantages are most pronounced in complex conceptual domains involving system interactions and spatial reasoning, precisely the areas that are most challenging in hybrid powertrain education.

Combined with substantial cost advantages over five years and enhanced resilience to infrastructure challenges common in Nigerian technical education, these findings suggest that VR represents not merely an acceptable alternative to physical training systems, but potentially a superior approach for technical education in Rivers State polytechnics. However, the differential advantages across knowledge domains and institutional contexts suggest

that optimal training might involve a blended approach, particularly for advanced students.

For policy makers and educational administrators in Rivers State, these findings support strategic investment in VR infrastructure as a cost-effective path toward modernizing technical education, particularly in specialized fields where physical equipment costs are prohibitive. For polytechnic instructors, the results highlight the importance of conceptual understanding and system visualization in supporting long-term knowledge retention and transfer.

Recommendations

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

1. Implement a mixed-methods longitudinal study design with both immediate and delayed (3-month, 6-month, 12-month) knowledge assessments to accurately measure retention differences between VR and physical training approaches.

2. Develop culturally relevant assessment instruments that evaluate both theoretical understanding and practical diagnostic skills, validated by local automotive industry experts from Port Harcourt and Bonny areas.

3. Account for varying digital literacy levels among students by incorporating a pre-study technology familiarization period, especially for VR interfaces which may be novel to many participants.

4. Create controlled experimental conditions that isolate the delivery medium (VR vs. physical) while maintaining identical content, instructional time, and learning objectives across both groups.

5. Partner with local automotive service centers to establish real-world performance metrics for graduates from both training methodologies, measuring actual diagnostic accuracy and efficiency when working with hybrid powertrains.

6. Address potential infrastructure challenges (power reliability, connectivity) by designing VR systems that can function in environments with intermittent electricity—potentially including battery backups and offline operation modes.

7. Incorporate Nigerian-specific vehicle models and common regional powertrain issues into both training platforms to maximize ecological validity and practical application for the local context.

8. Utilize a counterbalanced crossover design where students experience both training methods sequentially to control for individual learning differences while providing direct comparative data.

9. Analyze cost-benefit ratios specific to the Rivers State context, considering initial investment, maintenance requirements, and long-term sustainability of both educational approaches.

10. Develop a knowledge transfer protocol between participating polytechnics to share findings and best practices, potentially creating a Rivers State standard for hybrid powertrain education that optimizes the most effective elements of both VR and physical training.

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