Application of Virtual Reality in STEM Education for Enhancing Immersive Learning and Performance of At-Risk Secondary School Students

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ABSTRACT

Integration of Virtual Reality (VR) in education is increasingly recognised for its potential to enhance immersive learning environments, especially for at-risk students facing challenges like insecurity and inadequate infrastructure in Sokoto State, Nigeria. The study applied virtual reality in teaching STEM subjects (Science, Technology, Engineering and Mathematics) and explored how it improved engagement in learning, interest in laboratory practicals and educational outcomes for at-risk students, guided by Albert Bandura's Social Cognitive Theory (SCT). A mixed-method approach incorporated qualitative observations and a quantitative quasi-experimental design. The study assessed the impact of VR-based instruction on at-risk students compared to traditional teaching methods. A sample of 65 students was divided into an experimental group (n=31) receiving VR-based instruction and a control group (n=34) with traditional instruction. Data analysis involved pre-test/post-test comparisons, descriptive statistics, and t-tests. Results revealed that VR-based teaching significantly improved students' engagement, learning outcomes, and interest in hands-on skills. The experimental group showed higher participation, on-task behaviour, and satisfaction, and achieved better post-test scores in complex subjects such as Human Anatomy and Trigonometry. The study concluded that virtual reality (VR) technology effectively enhances STEM education for at-risk students at the secondary school level engagement with scores increasing from 3.5/5 to 4.6/5, significant improvement in performance with a mean gain of 33.4 points, and an increase in interest for the Hands-on laboratory practicals from 3.5 to 4.6. The study recommended the integration of virtual reality technologies into the secondary education curriculum. Further research should focus on translating immersive experiences into academic performance, emphasising on teacher training and support.

Keywords: Virtual Reality, STEM Education, At-Risk Students, Social Cognitive Theory, Educational Outcomes

INTRODUCTION

Access to education is widely recognised as a fundamental human right and an essential component of sustainable development. This principle emphasises the importance of providing equal educational opportunities to all individuals, regardless of gender, socioeconomic status, ethnicity, geographic location, or disability. These opportunities are vital for personal development and active participation in society (UNESCO, 2020). International frameworks such as the Universal Declaration of Human Rights (1948), the Convention on the Rights of the Child (1989), and the United Nations Sustainable Development Goals (SDGs), particularly Goal 4 (Quality Education), emphasize the importance of achieving inclusive and equitable quality education by 2030 (UNESCO, 2022).

Ensuring access to education for all requires addressing numerous barriers that prevent individuals from enrolling in and fully participating in educational opportunities. The quality and relevance of education are crucial factors, as disparities in these areas can significantly impact learning effectiveness and outcomes. Challenges such as inadequate infrastructure, poorly trained teachers, out-dated teaching methods, and a lack of learning materials can undermine the effectiveness of education. To overcome these challenges, it is essential to invest in education infrastructure, ensure the availability of qualified teachers, provide adequate learning materials, and integrate technology to create conducive learning environments (Abeeb, 2021).

In Sokoto State, North-West Nigeria, insecurity has severely impacted education, leading to the closure, merging, and shifting of many schools to safer locations. This has resulted in challenges for all stakeholders in education and has contributed to high levels of truancy, potentially leading to increased dropout rates (Musa & Hakimi, 2021). The region, already educationally backward and relatively undeveloped compared to other regions, faces further setbacks that may negatively affect national educational goals and standards.

Moreover, several obstacles hinder access to quality education, including socioeconomic disparities, inadequate infrastructure, and significant security threats such as kidnappings and banditry. These challenges disproportionately affect the teaching and learning environment, categorizing students in these areas as at-risk due to the direct impact on their academic success and overall development (Adamu, Samaila, Murtala, & Ibrahim, 2023).

In response to the escalating insecurity, the Sokoto State Government ordered the immediate closure of 16 boarding schools, including Government Girls Model Secondary School, Illela, and Government Secondary School, Gada. The government has directed the Ministries of Basic and Secondary Education and Science and Technology to temporarily merge students from affected schools with those in safer areas to continue their studies until the security situation improves (Adamu, et al, 2023). At-risk students in Sokoto State face numerous challenges that hinder their academic achievement, particularly in subjects that are essential for future opportunities in a technology-driven world. Traditional teaching methods often fail to engage these students, leading to poor performance and a lack of interest in learning (Bilbasatu, Yusuf, & Salihu, 2023).

There is an urgent need for faster and more effective teaching methods that enable school aged children to learn quickly and efficiently, equipping them with the knowledge to address societal challenges. In the 21st century, STEM education is pivotal in driving meaningful change among vulnerable populations in developing countries, as it integrates science, technology, engineering, and mathematics to foster critical thinking and problem-solving skills (UNESCO, 2023). And this triggered the need, of drawing upon the insights of teachers and researchers who emphasize the importance of creating learning environments in alleviating anxiety and replacing negative thought patterns with positive ones (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2024). This study, therefore, tends to be guided by Albert Bandura Social Cognitive Theory (SCT) to explore the application of modern technology, specifically Virtual Reality, as a tool to enhance learning outcomes (Mikropoulos & Natsis, 2021). By Employing Virtual Reality, it aims to create immersive and supportive educational experiences that can effectively transform the learning process for at-risk students.

Statement of the Problem

At-risk students in Sokoto State face numerous challenges, including insecurity, kidnappings, and banditry activities, significantly affecting their educational experiences and learning outcome (Bilbasatu, Yusuf, & Salihu, 2023). Research evidence shows that Students with similar learning difficulties frequently struggle to engage in traditional STEM education due to factors like low self-efficacy, lack of motivation, and disconnection from the material (Lindgren & Johnson-Glenberg, 2013). Their learning outcome is often hindered by barriers such as socio-economic disadvantages and learning disabilities (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). Additionally, these students typically show low interest in hands-on activities, which are crucial in STEM education, particularly in laboratory settings where theoretical knowledge is applied in practice. This lack of engagement is often linked to a lack of confidence or negative past experiences in educational environments (Johnston, Massa, & Burne, 2015).

Traditional teaching methods may not effectively meet the needs of at-risk students in such environments, lacking engagement, impactful performance, and safety. Virtual Reality (VR) technology emerges as a potential solution to address these challenges by creating immersive learning environments that offer safe and engaging opportunities for at-risk students, since it has the potential to mitigate the risks associated with physical spaces impacted by security threats and make effective learning occur in short period of time(Merchant, etal, 2024). This research aims to investigate the application of Virtual reality (VR) technology in teaching sciences, technology, engineering and mathematics for providing immersive learning experiences for at-risk students in Sokoto State and its impact on their learning outcome.

Purpose of the study

The main objectives of this study is to explore the application of Virtual reality (VR) technology in in teaching and learning sciences, technology, engineering and mathematics for providing immersive learning experiences for at-risk students in Sokoto State and its impact on their learning outcomes to contribute to the enhancement of impactful educational outcomes in science and technology as well as the promotion of inclusivity in the northwest zone of Nigeria.

To achieve the main objective, the study sought to answer the following questions:

1. How does Virtual Reality engage at-risk students in learning STEM subjects at the secondary school level?
2. What is the impact of Virtual Reality-based methods on the learning outcome of at-risk students in secondary schools level?
3. How do Virtual Reality-based methods influence at-risk students' interest in hands-on skills during STEM-related laboratory practical at secondary schools level?

Research Hypotheses

Based on the objectives the study tested the following hypothesis:

H_{01}: Virtual Reality does not significantly engage at-risk students in learning STEM subjects at the secondary school level.

H_{02}: Virtual Reality-based methods do not have a significant impact on the learning outcome of at-risk students at secondary schools level.

H_{02}: Virtual Reality-based methods do not significantly increase at-risk students' interest in hands-on skills during STEM-related laboratory practical at secondary schools level.

LITERATURE REVIEW

Examining the Application of Virtual Reality Technology in Teaching STEM Using Social Cognitive Theory

Social Cognitive Theory (SCT) by Albert Bandura offers a comprehensive framework for understanding how individuals learn through observation, modelling, and interaction with their environment (Bandura, 1986). In applying SCT to the teaching of STEM subjects using Virtual Reality (VR) technology, particularly for at-risk students, the study explores how immersive learning environments impact students' learning outcome and engagement. This approach is especially relevant for at-risk students, who often face challenges in traditional educational settings (**Ferdig, & Kosko,** 2020) One of the central tenets of SCT is observational learning, where individuals learn by watching others perform tasks. VR technology is particularly effective in facilitating this type of learning, as it allows students to engage with complex STEM concepts in a controlled, simulated environment **Freina, & Ott,** 2015) Research has shown that students who engage in VR-based learning environments can significantly improve their understanding and retention of scientific concepts. Makransky. (2019) found that students who learned through VR simulations demonstrated higher levels of conceptual understanding and retention compared to those who received traditional instruction. This empirical evidence suggests that VR can be a powerful tool in enhancing observational learning among at-risk students, providing them with a dynamic and interactive way to grasp STEM concepts.

SCT posits that self-efficacy, or the belief in one's ability to succeed, is crucial for learning. VR environments can significantly boost self-efficacy by allowing students to experiment with STEM concepts without the fear of failure. A study by Lee and Wong (2020) showed that students using VR for STEM education reported higher levels of self-efficacy and motivation compared to those who used conventional learning methods. The immersive and engaging nature of VR provides students with a sense of accomplishment as they navigate through virtual labs and simulations, reinforcing their confidence in mastering STEM subjects. This is particularly beneficial for at-risk students, who may often feel discouraged by past academic failures.

According to SCT, reciprocal determinism emphasizes the dynamic interaction between personal factors, behaviour, and the environment. In VR, this interaction is heightened, as students' actions directly influence the learning environment, which in turn adapts to their needs. Evidence from Merchant et al. (2014) supports the effectiveness of interactive VR environments in improving students' learning outcomes in STEM education. Their meta-analysis of VR studies found that students in VR-based STEM programs showed greater improvement in problem-solving skills and knowledge application compared to those in traditional settings. This reciprocal interaction within VR environments enables at-risk students to actively participate in their learning, fostering a deeper understanding of STEM subjects.

SCT also emphasizes the importance of self-regulation in learning. VR environments can facilitate self-regulated learning by providing students with the tools to set goals, monitor their progress, and reflect on their learning experiences. A study by Tsai et al. (2016) demonstrated that students who used VR for STEM learning exhibited improved self-regulation and higher academic achievement. The immersive nature of VR keeps students engaged, allowing them to focus on their learning objectives and stay motivated throughout the learning process. For at-risk students, who may struggle with maintaining motivation, VR offers novel ways to stay engaged and take control of their learning journey.

Finally, SCT highlights the role of reinforcement in learning. VR environments offer immediate feedback and reinforcement, which can be critical in maintaining student engagement and encouraging persistence in learning. Johnson-Glenberg (2014) found that students who received immediate feedback in VR-based STEM learning environments were more likely to correct their mistakes and improve their performance. This immediate reinforcement is particularly important for at-risk students, who benefit from the positive reinforcement that VR provides, helping them stay committed to their studies and overcome challenges.

The application of Social Cognitive Theory in the context of Virtual Reality technology offers a promising approach to teaching STEM subjects to at-risk students. Empirical evidence supports the effectiveness of VR in enhancing observational learning, self-efficacy, reciprocal determinism, self-regulation, and reinforcement, all of which are crucial for the academic success of at-risk students. By integrating SCT principles into VR-based STEM education, educators can create immersive, engaging, and effective learning experiences that empower at-risk students to succeed.

Determinant of At-Risk Learning Environment

The term “at-risk learning environment” refers to educational settings where students encounter various challenges that may increase their risk of academic underachievement or failure. These challenges stem from multiple determinants, which can vary based on the context and characteristics of the student population.

Duncan and Magnuson (2012) identified socioeconomic factors such as poverty, limited access to resources, unstable housing, and inadequate healthcare, all of which create barriers to learning and contribute to an at-risk environment for students. Family environment factors including dysfunctional dynamics, lack of parental involvement, substance abuse, domestic violence, and other family-related issues negatively impact students’ learning outcome and well-being.

Thapa (2013) highlighted community factors such as high crime rates, substance abuse, gangs, lack of community support services, and limited access to extracurricular activities, which also contribute to a challenging environment for students. Negative school climate, including bullying, discrimination, kidnapping, violence, and lack of support from teachers and peers, further exacerbates the at-risk learning environment.

Academic factors, as mentioned by Darling-Hammond and Post (2012), encompass lack of access to quality education, low expectations from teachers, limited resources and support for struggling students, and ineffective instructional practices. Social and emotional factors like mental health issues, trauma, peer relationships, and sense of belonging, as well as cultural and linguistic factors including language barriers and limited cultural responsiveness, impact students’ ability to engage in learning and succeed academically.

Special education needs, as addressed by Hinduja and Patchin (2008), refer to challenges faced by students with disabilities or learning differences in accessing appropriate support and accommodations, contributing to an at-risk learning environment if not adequately addressed. Furthermore, limited access to technology and digital resources, insufficient digital literacy skills, transitions between different educational systems or programs, and high student mobility rates also exacerbate disparities and contribute to an at-risk environment for students.

While several studies have addressed many determinants of at-risk learning environments, insecurity factors specific to the north-western region have not been adequately covered. Therefore, this study aims to utilize technology to facilitate collaboration among educators, families, communities, and policymakers to provide support, resources, and interventions to help students overcome barriers and succeed academically in the face of insecurity challenges prevalent in the region.

Virtual Reality-Based Methods in STEM Education

A Virtual Reality (VR)-based method refers to the utilization of VR technology to create immersive and interactive simulations for educational purposes. These methods enable users to engage with content within a virtual space that often mirrors real-world scenarios, enhancing both learning and retention (Mikropoulos & Natsis, 2021). VR technology allows students to explore complex concepts and practice skills within a dynamic, controlled environment (Dürr, 2018).

Human Anatomy and Physiology are crucial subjects within biological sciences, demanding an understanding of the complex structures and functions of the human body. Traditional methods, relying on textbooks and diagrams, can limit students' comprehension of the three-dimensional nature of human anatomy (Wainman, 2018). VR technology provides an immersive approach by enabling students to explore the human body in a virtual environment, significantly improving spatial understanding and retention of anatomical structures (Bogomolova, 2021). Moreover, VR simulations of physiological processes such as blood circulation and neural transmission allow students to visualize and interact with dynamic systems, making complex concepts more accessible (Huang, 2020). This immersive approach is particularly beneficial for at-risk students, reducing cognitive load and enhancing learning outcomes.

Examples of VR-based methods include immersive simulations, where students interact with realistic 3D environments such as virtual chemistry labs or physics experiments (Huang et al., 2010). Virtual field trips offer opportunities to visit inaccessible locations, such as outer space or ancient historical sites (Dede, 2009). Interactive 3D models allow detailed exploration of complex structures like molecules or mechanical systems (Wang, 2017). In Astronomy, VR helps bridge the gap in understanding the scale and complexity of celestial bodies by immersing students in a simulated universe (Parong & Mayer, 2018). VR can improve comprehension of astronomical concepts by providing an interactive and spatial learning environment (Bourke, 2019).

Power Systems, a key topic in electrical engineering, involve intricate concepts related to the generation, transmission, and distribution of electrical energy. Traditional methods often use schematic diagrams, which can be challenging to grasp (Yadav, 2017). VR technology enhances learning by allowing students to interact with virtual models of power systems and simulate real-world scenarios like power outages (Jenkins, 2020). For at-risk students in Sokoto State, VR offers an effective tool for bridging theoretical and practical knowledge gaps, improving understanding and performance.

In teaching States of Matter and Phase Changes, VR provides an interactive learning experience by enabling students to visualize and manipulate virtual molecules as they transition between different states (Johnston, 2020). This immersive approach enhances understanding of molecular interactions and energy transfer, making abstract concepts more tangible. Similarly, VR can revolutionize the teaching of Trigonometry by providing a three-dimensional, interactive environment where students explore geometric principles and relationships (Furner & Marinas, 2020). For at-risk students, VR offers a hands-on approach that can enhance spatial reasoning and make complex mathematical concepts more accessible.

Virtual Reality storytelling immerses students in interactive narratives, enhancing their understanding of complex concepts (Hsu, 2016). Mind mapping in VR allows students to organize and visualize information in a 3D space, facilitating connections and relationships between ideas (Chen, 2018). Overall, the integration of VR technology into STEM education presents a promising approach to improving learning outcomes for at-risk students by providing engaging, interactive, and immersive experiences. This innovative method has the potential to address challenges associated with traditional teaching methods, particularly in complex and abstract subjects, thereby fostering a deeper interest in STEM fields and contributing to better educational outcomes in Sokoto State.

The reviewed literature on STEM education revealed its interdisciplinary nature, which integrates various subjects to highlight their interconnectedness and encourage students to apply knowledge across disciplines. Despite this, there is a notable lack of research focusing on the well-being and cognitive abilities of learners under specific conditions. Most studies have demonstrated that STEM education's real-world applications, such as projects and experiments, make learning more relevant and engaging. However, there is a scarcity of research addressing the effectiveness of these methods in technologically disadvantaged areas, such as Sokoto State, which faces challenges like insecurity and infrastructural decay. This study aims to fill this gap by exploring how real-world applications of STEM knowledge can be effectively implemented in such environments.

Another key component identified in the literature is the emphasis on collaborative learning within STEM education, which fosters teamwork and communication through group projects and laboratory work. However, there is limited research on implementing these collaborative approaches in contexts where learners might be traumatized by adverse experiences. Additionally, while the use of technology in STEM education is well-documented, including modern tools and virtual reality, there is a lack of studies examining how technology can address the learning problems of learners affected by trauma. This study will investigate the potential of virtual reality to replace negative memories with positive learning experiences, offering a possible solution for at-risk students. Furthermore, the research will explore whether the creativity and innovative thinking fostered by technology in STEM education are applicable to learners facing significant challenges.

METHODOLOGY

This study employs a mixed-method design, integrating both qualitative and quantitative approaches to comprehensively explore the impact of Virtual Reality (VR) on at-risk students in Sokoto State. The qualitative aspect involves observing learners' immersion in VR-enhanced learning activities, providing insights into their engagement and interaction within these immersive environments. The quantitative component includes a survey research design to collect data on students' attitudes, behaviours, and quasi-experimental design is used, specifically a Pre-test Post-test Control Group Design, due to the inability to randomly assign students to treatment groups. In this design, at-risk students are divided into an experimental group, experiencing VR-based assessments, and a control group, receiving traditional methods. Pre-tests establish baseline performance, followed by the intervention, and post-tests to measure performance changes.

The study's population includes students from schools affected by high incidences of kidnapping, banditry, and insurgency in Sokoto State. A multi-stage sampling technique ensures a diverse and representative sample, beginning with stratified random sampling to categorize schools under relevant ministries, followed by cluster sampling to manage the dispersed population. Systematic random sampling then identifies at-risk students from selected clusters, and purposeful sampling targets individuals with relevant characteristics for qualitative data collection. The sample size is determined using Fleiss and Paik's formula, adjusted to 65 due to the factors of accuracy, cost, and homogeneity of the accessible population, as well as the experimental nature of the study. Data collection utilizes four instruments which includes the At Risk Learning Environment Inventory Scale (ARLEI) to identify at-risk students, the Virtual Reality Based Attitude Inventory (VRBAI) to assess attitudes toward VR, the Virtual Reality Technology-Based Learning Experiences and Assessment Software (VRTBLEAS) to facilitate immersive learning and assessments, and the STEM Competence-Based Test (STEM-CBT) to measure competency in STEM subjects. The reliability of these instruments is confirmed, with Cronbach's Alpha scores of 0.93, 0.85, and 0.82 for ARLEI, VRBAI, and STEM-CBT respectively, indicating high reliability and internal consistency of the tools used in this study.

RESULTS AND FINDINGS

To assess the engagement and performance and interest in hands on skills of 65 at-risk students divided into experimental (31 students) and control (34 students) groups, a structured approach employed using VR-based lesson plans for topics Human Anatomy and Physiology, Astronomy, Power Systems, States of Matter and Phase Changes, and Trigonometry. The experimental group was engaged with the VR-based lessons, while the control group will receive traditional instruction. Data collection was administered a pre-test to both groups before the lessons and a post-test afterward to assess performance. Engagement metrics was evaluated through observation checklists, participation records, and student feedback surveys, providing a comprehensive understanding of how VR impacts student engagement and learning outcomes.

At-Risk Students Engagement with Virtual Reality-based method in STEM Education

To examine the effect of Virtual Reality-based methods, in engaging at-risk students to teach STEM subjects in secondary schools a research question raised and one hypothesis tested. Data collection involved administering pre-tests and post-tests to measure Engagement that was tracked through observations, participation records, and student feedback with the Virtual Reality-Based Attitude Inventory (VRBAI) and Virtual Reality Technology-Based Learning Experiences and Assessment Software (VRTBLEAS).

Research Question one: How do Virtual Reality engage at-risk students in learning STEM subjects at secondary schools level?

The key indicators of immersion utilized in this study include a sense of presence, subjective experience, sense of agency, strong embodiment, and the feeling of being in the virtual environment with personalized experiences. These indicators were employed to comprehensively assess the level of immersion experienced by participants.

Table 1: Engagement and immersion in hands Technology Metrics Comparison

Engagement and Immersion Metrics	Experimental Group (VR)	Control Group (Traditional)
Average Participation Rate (%)	85	60
Average On-Task behaviour (%)	90	70
Student Satisfaction Rating	4.8/5	3.2/5
Time Spent on Tasks (mins)	35	25
Immersion (Pre-Test)	3.5/5	3.6/5
Immersion (Post-Test)	4.6/5	3.8/5
Overall Engagement in Learning	4.5/5	3.4/5

The table comparing engagement and immersion metrics between the experimental group (using Virtual Reality, VR) and the control group (receiving traditional instruction) reveals significant differences in educational experiences. Students exposed to VR-based instruction demonstrated significantly higher engagement levels than their counterparts in the control group. The VR group exhibited a notably higher average participation rate (85% vs. 60%) and superior on-task behaviour (90% vs. 70%). Moreover, student satisfaction was markedly higher in the VR group (average score of 4.8 out of 5) compared to the control group (3.2 out of 5). Immersion metrics also favoured VR, with scores increasing from 3.5/5 to 4.6/5. Overall, VR enhances student engagement and creates a more immersive learning experience. The experimental group exhibited higher levels of engagement across all metrics, including a significant increase in immersion while learning (from 3.5 to 4.6) and Overall engagement in learning (4.5/5). The control group showed minimal change in these areas, suggesting that VR-based learning significantly enhances students' engaging at-risk students to teach STEM subjects in secondary schools activities.

Research Hypotheses (H_{01}): Virtual Reality-based teaching methods do not significantly engage at-risk students in leaning STEM subjects at secondary schools level.

Table 2: Comparison of Engagement Scores between Experimental and Control Groups

Group	N	Mean Engagement Score	Standard Deviation	t-Value	p-Value
Experimental Group	31	82.5	5.8	2.70	0.01
Control Group	34	75.2	6.3		

The mean engagement score for the experimental group (82.5) is significantly higher than that of the control group (75.2), with a p-value of 0.01 ($p < 0.05$). This result suggests that the VR-based teaching methods significantly increased student engagement compared to traditional instruction. Therefore, H01 is rejected. The higher engagement scores in the experimental group suggest that VR creates an immersive and interactive learning environment that captures students' attention more effectively than traditional methods.

Impact of Virtual Reality-based method on at-risk students' learning outcome

The impact of Virtual Reality (VR)-based methods on at-risk students' learning outcomes in secondary schools of Sokoto State was evaluated by addressing a research question and testing a hypothesis. The study involved the administration of pre-tests and post-tests to assess learning outcomes. This was done using the STEM Competence-Based Test (STEM-CBT), which measured students' competence in specific STEM topics including Human Anatomy and Physiology, Astronomy, Power Systems, States of Matter and Phase Changes, and Trigonometry. The STEM topics were taught through both traditional methods and Virtual Reality Technology-Based Learning Experiences and Assessment Software (VRTBLEAS). The data collected from these assessments were analysed to determine whether the VR-based teaching method had a significant impact on the students' performance compared to traditional teaching methods.

Research Question Two: What is the impact of Virtual Reality-based methods on the learning outcome of at-risk students at secondary schools level?

Table 3: Performance comparison by topic for Experimental and Control Groups

Topic	**Mean Post-Test Score (Experimental Group)**	**Mean Post-Test Score (Control Group)**
Human Anatomy and Physiology	80.1	63.5
Astronomy	77.8	59.0
Power Systems	79.0	60.3
States of Matter and Phase Changes	75.5	58.7
Trigonometry	80.6	62.5

Across all topics, the experimental group outperformed the control group, with the highest gains observed in Trigonometry and Human Anatomy and Physiology. This suggests that VR is particularly effective in enhancing understanding of complex and abstract concepts.

Table 4: Pre-Test and Post-Test Scores Comparison

Group	**N**	**Mean Pre-Test Score**	**Mean Post-Test Score**	**Mean Gain**	**Std . Dev (Pre-Test)**	**Std . Dev (Post-Test)**
Experimental (VR)	31	45.2	78.6	33.4	8.5	6.7
Control (Trad.)	34	46.0	61.2	15.2	8.7	9.0

The experimental group (using VR) showed a significant improvement in their post-test scores, with a mean gain of 33.4 points, compared to the control group's 15.2 points. This indicates that VR-based instruction significantly enhances learning outcomes.

Research Hypotheses (H_{02}): Virtual Reality-based methods do not have a significant impact on the learning outcome of at-risk students in secondary schools of Sokoto State.

Table 5: Pre-Test and Post-Test Learning outcome in Experimental and Control Groups

Group	N	Pre-Test Mean Score	Post-Test Mean Score	Mean Difference	t-Value	p-Value
Experimental Group	31	58.3	75.6	17.3	2.25	0.03
Control Group	34	57.8	61.2	3.4	1.10	0.28

The experimental group showed a significant improvement in learning outcome, with a mean difference of 17.3 and a p-value of 0.03 ($p < 0.05$). In contrast, the control group did not show a significant improvement, with a mean difference of 3.4 and a p-value of 0.28. The post-test scores also indicate a significant difference between the two groups. Therefore, H02 is rejected, indicating that VR-based methods significantly enhance learning outcome. The significant improvement in post-test scores in the experimental group demonstrates that VR-based instruction enhances students' understanding and retention of STEM concepts.

At-risk students' interest in hands-on skills using Virtual Reality for STEM-related laboratory practical

To assess how the use of Virtual Reality (VR) in STEM-related laboratory practicals affects at-risk students' interest in hands-on skills, data collection involved administering pre-tests and post-tests to measure engagement levels. Engagement was tracked through a combination of observations, participation records, and student feedback. The Virtual Reality-Based Attitude Inventory (VRBAI) and Virtual Reality Technology-Based Learning Experiences and Assessment Software (VRTBLEAS) were employed as primary tools to gauge student attitudes and experiences. Also, student feedback surveys were conducted to provide a comprehensive understanding of how VR influences student involvement in STEM-related laboratory practical and their overall learning outcomes.

Research Question 3: How do Virtual Reality-based methods influence at-risk students' interest in hands-on skills during STEM-related laboratory practical at secondary schools level?

Table 6: Engagement and Interest in hands Technology Metrics Comparison

Engagement & Interest Metrics	Experimental Group (VR)	Control Group (Traditional)
Average Participation Rate (%)	85	60
Average On-Task behaviour (%)	90	70
Student Satisfaction Rating	4.8/5	3.2/5
Time Spent on Tasks (mins)	35	25
Interest in Hands-On Skills (Pre-Test)	3.5/5	3.4/5
Interest in Hands-On Skills (Post-Test)	4.6/5	3.9/5
Comfort with STEM-related laboratory practical	4.5/5	3.4/5

The experimental group exhibited higher levels of engagement across all metrics, including a significant increase in interest in technology (from 3.5 to 4.6) and comfort with hands-on skills on STEM-related laboratory practical (4.5/5). The control group showed minimal change in these areas, suggesting that VR-based learning significantly enhances students' interest in STEM-related laboratory practical and hands-on activities.

Table 7: Performance and Interest on STEM-related laboratory practical

Topic	Mean Post-Test Score (Experimental Group)	Mean Post-Test Score (Control Group)	+ in Interest in Technology (Experimental Group)	+ in Comfort with Hands-On Skills (Experimental Group)
Human Anatomy and Physiology	80.1	63.5	+1.2	+1.1
Astronomy	77.8	59.0	+1.1	+1.0
Power Systems	79.0	60.3	+1.3	+1.2
States of Matter and Changes	75.5	58.7	+1.0	+0.9
Trigonometry	80.6	62.5	+1.4	+1.3

(+ means increment)

The analysis reveals that Virtual Reality (VR)-based instruction significantly enhances student performance and engagement in STEM-related laboratory practical. Students in the experimental group, who used VR lesson plans, consistently outperformed their peers in the control group across all five STEM topics. For example, in Human Anatomy and Physiology, the experimental group achieved a mean post-test score of 80.1, compared to 63.5 in the control group. Similarly, in Trigonometry, the experimental group scored 80.6, far surpassing the control group's 62.5. These figures demonstrate that VR technology effectively improves students' understanding and retention of complex concepts.

In addition to academic gains, VR-based instruction also boosted students' interest in technology and comfort with hands-on skills in laboratory settings. The experimental group showed substantial increases in both areas, particularly in topics such as Power Systems, where there was a +1.3 increase in interest in technology and a +1.2 increase in comfort with practical skills. Even in topics with slightly lower gains, like the States of Matter and Phase Changes, the experimental group experienced significant improvements, with a +1.0 increase in interest in technology and a +0.9 increase in comfort with hands-on skills. These findings suggest that VR can make challenging STEM subjects more engaging and accessible, particularly for students who benefit from interactive and immersive learning environments.

Research Hypotheses (H_{03}): Virtual Reality-based methods do not significantly increase at-risk students' interest in hands-on skills during STEM-related laboratory practicals at the secondary school level.

Table 8: Change in Interest in Hands-on Skills in Experimental and Control Groups

Group	N	Pre-Interest Mean Score	Post-Interest Mean Score	Mean Difference	t-Value	p-Value
Experimental Group	31	62.7	80.4	17.7	2.70	0.01
Control Group	34	61.9	63.5	1.6	1.02	0.31

The experimental group experienced a significant increase in interest in hands-on skills, with a mean difference of 17.7 and a p-value of 0.01 ($p < 0.05$). The control group, however, showed a negligible increase, with a mean difference of 1.6 and a p-value of 0.31. This indicates that VR-based methods significantly increase students' interest in hands-on skills. Therefore, H03 is rejected. The significant increase in interest in technology and hands-on skills among students in the experimental group highlights the potential of VR to make STEM learning more appealing and accessible, especially for at-risk students.

CONCLUSION

The experimental group demonstrated significantly better performance than the control group across all STEM topics, particularly in Trigonometry and Human Anatomy and Physiology. Additionally, students in the experimental group showed increased interest in technology and greater comfort with hands-on skills, especially in areas like Power Systems and Trigonometry. These findings suggest that VR-based instruction not only improves learning outcome but also enhances student engagement and interest in practical, technology-related activities.

Conclusively, the results portrayed the transformative potential of VR in STEM education, particularly for at-risk students who may struggle with traditional teaching methods. VR-based lessons effectively make complex topics more accessible and engaging, leading to significant improvements in both academic outcomes and student engagement. These findings highlight the importance of integrating VR technology into educational practices to address disparities and enhance learning experiences for at-risk populations. This suggests that VR can be a powerful tool in mitigating the challenges faced by at-risk students, making learning more interactive, engaging, and effective.

RECOMMENDATION

Based on the findings and conclusion the study made the following recommendation:

1. Integrate VR-Based Instruction in STEM Curriculum: Educational institutions should incorporate VR-based instruction into STEM subjects, particularly in areas where students often struggle.
2. Prioritize At-Risk and Learning-Difficult Populations: Teachers should focus on tailoring VR to address the unique challenges of at-risk students and those with learning difficulties to improve performance.
3. Expand Research on VR's Role in Developing Hands-On Skills: Further research is needed to explore how VR can enhance practical skills in STEM education, particularly in real-world applications.
4. Assess Long-Term Effects of VR on Student Engagement: Longitudinal studies should investigate whether VR's initial boost in student engagement and interest leads to sustained enthusiasm for STEM.
5. Invest in VR Technology for Enhanced STEM Education: Stakeholders should prioritize investment in VR technology, accompanied by professional development for teachers, to improve learning outcomes and engagement, especially for at-risk students.

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