



Efficacy of Virtual Reality Simulation-Based Instruction on Students' Academic Achievement in Ecology in Oye Local Government Area, Ekiti State

Folasade Oluyemisi Olayinka¹, Ayodele Samson Osunsemi¹, Alexander Oluwagbemiro Ala¹,
Geoffrey Ukala^{2*}

¹Department of Science Education, Federal University, Oye-Ekiti, Ekiti State, Nigeria

²University of Nigeria, Nsukka, Nigeria

*Corresponding author: geoffrey.ukala@unn.edu.ng

Abstract

This study investigated the efficacy of virtual reality simulation-based instruction on students' academic achievement in ecology in Oye Local Government Area, Ekiti State. Three research questions and hypotheses guided the study. A quasi-experimental pretest-posttest control group design was adopted. The population comprised all Senior Secondary School Two (SS2) students offering Biology in public secondary schools in the state. A total of 65 SS2 students (35 in the experimental group and 30 in the control group) participated in the study. Participants in the experimental group were taught using VRSI, while the control group received instruction using a conventional method, and the treatment lasted for six weeks. Data were collected using a researcher-designed Ecology Achievement Test (EAT), and were validated by three experts. EAT reliability was established using the Kuder-Richardson Formula 20, yielding a coefficient of 0.83. In analyzing the data, the mean and standard deviation were used to answer the research questions. In contrast, independent-samples *t* tests were used to test the hypotheses at the .05 significance level. The results revealed that students exposed to Virtual Reality Simulation-Based Instruction obtained significantly higher posttest achievement scores than those taught conventionally, $t(63) = 5.66, p < .001, d = 1.41$. They also recorded significantly higher mean gain scores, $t(63) = 3.93, p < .001, d = 0.98$. There was no significant influence of gender on students' academic achievement in ecology when taught using VRSI, $t(33) = -0.71, p = .484$. It is thus recommended that Biology teachers should employ Virtual Reality Simulation-Based Instruction strategies to teach ecological concepts.

Keywords: virtual reality, simulation-based instruction, Biology, ecological concepts, academic achievement.

1 Introduction

Biology is a fundamental component of the secondary school science curriculum, which equips learners with relevant knowledge and understanding of living things, their structure, functions, interactions, and relationships with their environment. Biology plays a key role in national development due to its relevance to health, agriculture, and environmental sustainability, making it the most vital and popular science subject (Ukala et al., 2026). The knowledge of Biology, especially ecological concepts, empowers learners with the right attitude toward the environment and its sustainability. According to Shutaleva (2023), understanding ecological processes is the key to developing environmentally literate citizens who can effortlessly think critically about environmental issues and make informed decisions for sustainability. Despite the importance of biology, particularly ecology, to individual and national development, students' performance has maintained a steady and devastating decline in recent years.

Students complain that ecological concepts are not always easy to comprehend due to their abstract, complex, dynamic, and interconnected relationships that are not readily observable in the classroom (Sembiring & Yusuf, 2025; Eberbach et al., 2021). Implying that learners construct mental models of various ecological phenomena, such as energy flow, relationships between populations, and environmental changes, only in their imagination. These challenges have been linked to the dominant use of conventional teaching methods by most teachers (Ukala et al., 2026). In agreement, Dey and Munshi (2025) opined that when instruction is delivered solely through verbal explanations, textbooks, and static images, learners often struggle to assemble the parts of an ecosystem and create meaningful representations of how they

fit together. Conventional methods, which rely on the talk-chalk-talk approach to instruction, are not completely ineffective, but they remain ineffective at promoting understanding of ecological concepts.

It limits students' opportunities to participate in practical activities, experiments, and ecological field visits, especially in resource-constrained contexts where organizing such experiences can be challenging due to logistical difficulties (Honra, 2026). Consequently, students learn about ecological phenomena through descriptions and representations rather than direct interaction, leading to a weak link between the principles they learn and the tangible processes that unfold in nature. The need for alternative instruction, such as Innovative Visualization Technology (IVT), to improve learning outcomes among students cannot be overstated. IVTs have emerged to address some of the limitations of the conventional method of instruction. Among the IVTs, Virtual Reality (VR) is a technology that enables learners to immerse themselves in computer-generated virtual environments with simulated objects, places, and events (Noor, 2026).

Virtual Reality (VR) offers immersive, interactive environments that allow users to visualize, manipulate, and engage with realistic representations of phenomena that may otherwise be difficult, costly, unsafe, or inaccessible. According to Shirley et al. (2025), the use of virtual simulation tools has attracted increasing interest in science education as a means of visualization, experimentation, problem-solving, and concept acquisition. They, however, noted that IVTs appear to be more established in higher education rather than in primary and secondary science education in Nigeria. VR is especially relevant to Biology education because many biological structures and processes are spatial, dynamic, and not directly observable (Ewere, 2025). VR, such as 3D (three-dimensional) representations and interactive experiences, can facilitate the understanding of otherwise abstract and spatially complex content.

Empirical evidence suggests that VR in science learning enables learners to explore simulated ecological systems, observe the interactions that occur within them, witness environmental changes, and explore ecological interactions (Kang et al., 2025). It helps learners connect abstract ecological concepts to more concrete visual representations of ecological systems (Mayer, 2005). However, it is important not to make assumptions about the learning benefits of VR because it can provide a sense of presence and immersion, which do not necessarily equate to a learning advantage. The benefit of VR depends on instructional design and the pedagogical approach adopted, and it should complement rather than substitute for a skilled teacher (Ukala et al., 2026; Alam & Mohanty, 2023).

Effective instruction involves directing students' focus, asking relevant questions, explaining concepts, and helping students make connections between their experiences in Virtual Reality (VR) and the intended learning outcomes. A review of VR and Augmented Reality (AR) applications in K-12 science classes concluded that, like any instructional tool, VR applications should be meaningfully integrated into the curriculum and used within a sound pedagogical framework (Elme et al., 2022; Mulders et al., 2020). Empirical evidence concerning whether VR can enhance learning is mixed: some researchers have reported positive results, while others have not observed a significant difference in achievement between students who received Virtual Reality (VR)-based instruction and those who did not (Zou et al., 2026).

In a meta-analysis, (Merchant et al. (2014) found that the effects of virtual reality instruction varied widely depending on the type of Virtual Reality (VR), the pedagogical approach, and the content being learned; the study also showed that desktop virtual environments can sometimes outperform immersive environments (Radianti et al., 2020). The researcher noted that the majority of studies on immersive Virtual Reality (VR) in higher education lacked a rigorous instructional design and theoretical underpinnings, limiting the generalizability of their findings. Overall, the effectiveness of Virtual Reality (VR) depends on the content, pedagogy, activity design, and context; therefore, it is necessary to evaluate its efficacy in specific subject areas, learner populations, and educational contexts. This research is relevant to Nigerian secondary school science education because many learners do not have access to well-equipped science laboratories or opportunities to visit the field due to resource limitations, logistical challenges, or safety concerns.

Simulated instruction may provide an alternative and potentially more accessible way to engage students with ecologically relevant phenomena through computer-mediated representations (Smetana & Bell, 2012). Yet, empirical data on the impact of Virtual Reality (VR)-based simulation instruction on secondary students' achievement in ecological concepts remain limited in Nigeria (Agbor et al., 2025). Specifically, there is not enough evidence to determine whether VRSI can significantly improve the achievement of Nigerian secondary school students in ecological concepts relative to conventional instruction (Usman, 2021). Furthermore, there has been limited attention to the potential difference in achievement between male and female learners following VRSI in Nigeria. This gender dimension is important because earlier studies have yielded inconsistent results regarding the influence of gender on Biology achievement in Nigeria,

with some studies showing a male advantage, others a female advantage, and others finding no gender difference (Okoye, 2016).

Determining whether VRSI provides equal advantages for male and female students is therefore crucial. It is this gap that this study seeks to address by examining the efficacy of virtual reality simulation-based instruction on students' academic achievement in ecology in Ekiti State

Specifically, the study sought to determine:

1. the mean achievement scores of students taught ecology using VRSI and those taught using the conventional teaching method.
2. the influence of gender on students' academic achievement in ecology when taught using VRSI and conventional teaching methods.

1.1 Research Questions

The following research questions guided the study:

1. what is the mean achievement scores of students taught ecology using VRSI and those taught using the conventional teaching method?
2. What is the influence of gender on students' academic achievement in ecology when taught using VRSI and conventional teaching methods?

1.2 Hypotheses

The following null hypotheses were tested at the .05 level of significance:

1. There is no significant difference in the mean achievement scores of students taught ecology using VRSI and those taught using the conventional teaching method.
2. There is no significant influence of gender on the mean academic achievement score in ecology when taught using VRSI and the conventional teaching method.

2 Methodology

2.1 Research Design

The study adopted a quasi-experimental pretest-posttest control group design. This design was considered appropriate because intact school classes were used rather than randomly assigning individual students to instructional conditions, which would have been disruptive to school timetables. The design enabled the researchers to compare the academic achievement of students exposed to Virtual Reality Simulation-Based Instruction (VRSI) with that of students taught using the conventional teaching method, while statistically controlling for pre-existing differences in achievement through the pretest. The design is symbolically represented as $O_1 X O_2$ for the experimental group and $O_1 C O_2$ for the control group, where O_1 represents the pretest, O_2 represents the posttest, X represents the treatment (VRSI), and C represents the control condition (conventional method).

2.2 Participants

The population of the study comprised all Senior Secondary School Two (SS2) students offering Biology in public secondary schools in Oye Local Government Area, Ekiti State, Nigeria. This population was chosen because SS2 is the level at which ecological concepts are taught in the Nigerian Biology curriculum, and students at this level are preparing for external examinations such as WAEC and NECO, where ecology features prominently. Two schools were purposively sampled based on the availability of SS2 Biology students, the availability of facilities to support the VR intervention, the willingness of school authorities to participate, and proximity to the researchers for logistical convenience. One intact class was used from each school, forming two groups: the experimental group and the control

group. The experimental group comprised 35 students (15 males and 20 females), while the control group comprised 30 students (16 males and 14 females), giving a total sample size of 65 students. Purposive sampling was used because the researchers needed schools with the technological infrastructure to support VR simulation, and intact classes were used to avoid disruption of school timetables and to prevent the Hawthorne effect that might arise from randomly selecting students.

2.3 Instrumentation

The instrument used for data collection was a researcher-developed Ecology Achievement Test (EAT). The EAT comprised 25 multiple-choice items covering ecological concepts such as energy flow and trophic levels, food chains and food webs, population dynamics, ecological relationships, nutrient cycling, and environmental changes and adaptation. Each item had four options (A–D), and each correct answer was worth 1 mark, while wrong answers were worth 0, giving a maximum obtainable score of 25. The face and content validities of the instrument were determined by three experts: one in Science Education, one in Educational Technology, and one in Measurement and Evaluation. They examined the items for clarity, readability, language appropriateness, coverage of ecological concepts, alignment with curriculum objectives, and cognitive-level appropriateness. Their comments led to the modification and removal of some items before final administration. The reliability of the EAT was established using the Kuder-Richardson Formula 20 (KR-20), which is appropriate for dichotomously scored items. A trial test was administered to 30 SS2 Biology students in a different school outside the study area but with similar characteristics, and the analysis yielded a reliability coefficient of 0.83, indicating high internal consistency (Zakariya, 2022).

2.4 Intervention

The intervention lasted six weeks, with two lessons per week, each lasting 40 minutes. The same Biology teacher taught both groups to control for the teacher effect. The teacher was trained for one week before the intervention on the use of the VR equipment and on the lesson procedures for both groups.

Week 1 (both groups): A pretest was administered to both groups. This was followed by an introduction to ecology and basic concepts, including the meaning of ecology, levels of ecological organisation, and the components of an ecosystem. Both groups received the same content and the same duration of instruction.

Weeks 2–5 (experimental group): The experimental group was taught using VRSI. Each lesson followed a structured five-step procedure:

1. Pre-simulation orientation (5 minutes): The teacher introduced the lesson objectives and the ecological concept to be explored, and asked probing questions to activate prior knowledge. Students were then briefed on how to use the Google Cardboard VR viewers and smartphones.
2. Guided simulation exploration (15 minutes): Students, working in pairs, wore the VR viewers and explored a simulated ecosystem relevant to the day's topic. For example, for energy flow and trophic levels, students navigated a 3D ecosystem and traced the movement of energy from producers to consumers. For population dynamics, students manipulated variables such as birth rate, death rate, food availability, and predation pressure, and observed the resulting changes in population size. For food chains and food webs, students constructed and modified food webs by dragging and linking virtual organisms. For nutrient cycling, students observed the movement of carbon and nitrogen through the biotic and abiotic components of the ecosystem. For environmental changes and adaptation, students altered environmental parameters such as temperature and rainfall and observed how virtual organisms responded over time.
3. Teacher-guided reflection and discussion (10 minutes): After the simulation, the teacher led a whole-class discussion in which students described what they observed, compared their observations with the ecological principles taught, and explained the relationships they noticed. The teacher used questions such as "What happened to the predator population when the prey population decreased?" and "Why did energy decrease at each trophic level?" to guide students toward the intended concepts.
4. Concept consolidation (5 minutes): The teacher summarised the key ecological principles, linked the simulation experience to the textbook content and curriculum objectives, and corrected any misconceptions that emerged during the discussion.

5. Formative assessment (5 minutes): Students answered short oral or written questions individually or in pairs to check understanding, and the teacher provided immediate feedback.

Weeks 2–5 (control group): The control group was taught the same ecological concepts using the conventional lecture method. The teacher used the chalkboard, textbooks, and static diagrams to explain concepts, and students listened, took notes, and answered questions. No simulation, VR equipment, or interactive manipulation of variables was used. The content coverage and instructional time were identical to those of the experimental group.

Week 6 (both groups): A posttest was administered to both groups using the same EAT used for the pretest, with items rearranged to reduce practice effects.

Ethical considerations were duly observed: informed consent was obtained from parents and guardians, as well as school authorities; ethical approval was obtained from the relevant research ethics committee; and students were assured of confidentiality and the right to withdraw at any time without penalty.

2.5 Data Collection and Analysis

Data were collected through the administration of the EAT as a pretest in Week 1 and as a posttest in Week 6. The researcher administered the instrument with the assistance of the trained Biology teacher, and scripts were retrieved immediately after each administration. Data collected were analysed using mean and standard deviation to answer the research questions. Before testing the hypotheses, the assumptions for parametric testing were examined. The Shapiro-Wilk test was used to assess normality of the achievement scores, and Levene's test was used to assess homogeneity of variances. The Shapiro-Wilk test indicated that the pretest and posttest scores for both the experimental and control groups were normally distributed ($p > .05$ for all distributions), and Levene's test indicated homogeneity of variances ($p > .05$). Given that the assumptions were met, an independent-samples t-test was used to test Hypothesis 1, and an independent-samples t-test was used to test Hypothesis 2 within the experimental group. Cohen's d was used to measure effect size because statistical significance alone does not indicate practical importance. All statistical analyses were performed in SPSS.

Although a pretest was administered, an independent-samples t-test was used rather than ANCOVA because the pretest scores of the two groups were not statistically significantly different, $t(63) = 0.84$, $p = .404$, indicating that the groups were equivalent at baseline. In addition, the use of ANCOVA with intact groups of unequal sizes and with a relatively small sample ($N = 65$) would have reduced statistical power. The t-test on posttest scores was therefore considered appropriate and parsimonious for the purpose of this study.

3 Results

3.1 Addressing Research Question 1

What is the difference in the mean achievement scores of students taught ecology using VRSI and those taught using the conventional teaching method?

Table 1

Mean and Standard Deviation of Posttest Achievement Scores by Instructional Strategy

Instructional Strategy			n	Mean	SD	Mean Difference
Virtual Reality Simulation-Based Instruction			35	20.29	3.49	5.32
Conventional Method			30	14.97	4.09	—
Total			65			

Table 1 shows that students exposed to Virtual Reality Simulation-Based Instruction obtained a higher posttest achievement mean ($M = 20.29$, $SD = 3.49$) than students taught using the conventional method ($M = 14.97$, $SD = 4.09$). The mean difference was 5.32 points, indicating higher posttest achievement among students exposed to VR Simulation-Based Instruction.

3.2 Addressing Research Question 2

What is the influence of gender on students' academic achievement in ecology when taught using VRSI and conventional teaching methods?

Table 2

Mean and Standard Deviation of Experimental-Group Posttest Achievement Scores by Gender

Gender	n	Mean	SD	MeanDifference
Male	15	19.80	4.04	0.85
Female	20	20.65	3.07	—
Total	35			

Table 2 shows that female students obtained a slightly higher posttest achievement mean ($M = 20.65$, $SD = 3.07$) than male students ($M = 19.80$, $SD = 4.04$). The descriptive mean difference was 0.85 points in favour of the female students.

3.3 Test of Hypotheses

Hypothesis 1

H₀₁: There is no significant difference in the mean achievement scores of students taught ecology using VRSI and those taught using the conventional teaching method.

Table 3

Independent-Samples t-Test of Posttest Achievement Scores

Group	n	Mean	SD	Levene's F	Levene's p	t	df	p	Mean Diff	95%CI	Cohen's d
Experimental	35	20.29	3.49	1.18	.281	5.66	63	<.001	5.32	[3.44,7.20]	1.41
Control	30	14.97	4.09								

Table 3 shows a statistically significant difference in posttest achievement scores between students exposed to VRSI and those taught using the conventional method, $t(63) = 5.66$, $p < .001$. The mean difference was 5.32 points, with a 95% confidence interval of [3.44, 7.20]. Cohen's $d = 1.41$ indicates a large effect. Therefore, H_{01} was rejected.

Hypothesis 2

H₀₂: There is no significant influence of gender on students' academic achievement mean score in ecology when taught using VRSI and conventional teaching method.

Table 4: Independent-Samples t-Test of Experimental-Group Posttest Achievement Scores by Gender

Gender	n	Mean	SD	Levene's F	Levene's p	t	df	p	Mean Diff	95%CI	Cohen's d
Male	15	19.80	4.04	0.09	.765	-0.71	33	.484	-0.85	[-3.29,1.59]	-0.24
Female	20	20.65	3.07								

Table 4 shows that the difference between male and female students' posttest achievement scores was not statistically significant, $t(33) = -0.71$, $p = .484$. The mean difference was -0.85, with a 95% confidence interval of [-3.29, 1.59]. Cohen's $d = -0.24$ indicates a small effect. Therefore, H_{02} was not rejected.

4 Discussion of Findings

The first finding of the study revealed that students taught ecological concepts using Virtual Reality Simulation-Based Instruction obtained significantly higher posttest achievement scores than those taught using the conventional teaching method. The mean difference of 5.32 points, $t(63) = 5.66$, $p < .001$, with a large effect size ($d = 1.41$), indicates that VRSI was substantially more effective than the conventional method in promoting students' understanding of ecology. This finding supports the contention that the interactive and engaging nature of VR simulation enhances students' visualization and comprehension of ecological concepts (Enchescu et al., 2026; Schwartz & Blau, 2026). The result is consistent with the cognitive theory of multimedia learning (Mayer, 2005) and dual coding theory (Paivio, 2014), which posit that learners understand better when information is presented through both visual and verbal channels simultaneously. VR simulation provides this dual-channel experience by allowing students to see and interact with ecological processes rather than merely hearing or reading about them.

The finding also aligns with Mafarja et al. (2026), who reported that interactive, exploratory simulations foster active exploration and conceptual understanding. Furthermore, the result corroborates the position of Smetana and Bell (2012) that computer simulations can support science instruction and learning effectively, particularly for abstract and dynamic concepts that are difficult to observe directly in the classroom. In the context of Nigerian secondary schools where ecological field trips and well-equipped laboratories are often unavailable due to logistical and resource constraints (Honra, 2026), VRSI offers a viable alternative for providing students with meaningful encounters with ecological phenomena.

The second finding revealed no statistically significant effect of gender on students' academic achievement in ecology when taught using VRSI, $t(33) = -0.71$, $p = .484$, $d = -0.24$. Although female students obtained a slightly higher mean score ($M = 20.65$, $SD = 3.07$) than male students ($M = 19.80$, $SD = 4.04$), the difference of 0.85 points was small and not statistically significant. This finding indicates that VRSI was equally effective for both male and female students, suggesting that the instructional strategy did not favour one gender over the other. This result is consistent with Okoye (2016), who noted that studies on gender and Biology achievement in Nigeria have yielded inconsistent results, with some showing male advantage, some female advantage, and others finding no difference. The present study aligns with those that found no significant gender difference. The finding also supports the view that well-designed technology-enhanced instruction can create equitable learning opportunities for all students regardless of gender.

Since VR simulation provides visual, interactive, and hands-on experiences that do not rely on prior gender-typed experiences or interests, it may help to level the playing field between male and female learners in science. This has important implications for promoting gender equity in science education, particularly in ecology, where both male and female students can benefit equally from the immersive and interactive features of VR.

5 Conclusion

The study concluded that Virtual Reality Simulation-Based Instruction is significantly more effective than the conventional teaching method in improving students' academic achievement in ecology. Students exposed to VRSI achieved higher posttest scores with a large effect size, indicating that the intervention had a substantial practical impact on learning outcomes. Furthermore, the study found no statistically significant influence of gender on achievement when students were taught using VRSI, suggesting that the strategy is equitable and beneficial for both male and female students. Based on these findings, it was concluded that VRSI is a promising instructional approach for teaching ecological concepts in secondary schools, particularly in resource-constrained contexts where direct field experiences and well-equipped laboratories are not readily available.

6 Recommendations

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

1. Biology teachers should employ Virtual Reality Simulation-Based Instruction strategies when teaching ecological concepts, especially for topics involving complex relationships, dynamic processes, and environmental interactions that are difficult to comprehend through traditional delivery methods.

2. Practical training on the pedagogical application of VR should be provided to Biology teachers. This training should not focus solely on the operation of VR equipment but should address lesson planning, guiding learners, questioning, leading discussions, and linking VR experiences with curriculum content. Curriculum developers and educational policymakers should consider integrating VR simulation-based resources into the Biology curriculum as supplementary instructional materials, particularly for topics that are abstract, dynamic, or inaccessible for direct observation.
3. School administrators should strive to provide the necessary technological infrastructure, such as smartphones, Google Cardboard viewers, and internet connectivity, to support the implementation of VRSI in Biology classrooms. Further research should be conducted with larger and more diverse samples across different states and educational levels to enhance the generalizability of the findings.

7 References

- Agbor, C. N., Etan, M. O., Akuji, R. T., & Ogbor, C. O. (2025). Methods of teaching environmental education for sustainability. *International Journal of Economics, Environmental Development and Society*, 6(2), 209–233.
- Alam, A., & Mohanty, A. (2023). Implications of virtual reality (VR) for school teachers and instructional designers: An empirical investigation. *Cogent Education*, 10(2), 2260676.
- Dey, A., & Munshi, S. A. (2025). Fun with images: an analysis of the role of visual literacy in facilitating easy and enjoyable learning with a focus on future prospects. *Libri*, 75(2), 109–127.
- Eberbach, C., Hmelo-Silver, C. E., Jordan, R., Taylor, J., & Hunter, R. (2021). Multidimensional trajectories for understanding ecosystems. *Science Education*, 105(3), 521–540.
- Elme, L., Jørgensen, M. L., Dandanell, G., Mottelson, A., & Makransky, G. (2022). Immersive virtual reality in STEM: is IVR an effective learning medium and does adding self-explanation after a lesson improve learning outcomes? *Educational technology research and development*, 70(5), 1601–1626.
- Ewere, C. R. (2025). Impact of virtual reality on learning complex biological processes: A study of secondary schools in Delta State, Nigeria. *Advances in Law, Pedagogy, and Multidisciplinary Humanities*, 3(2), 219–229.
- Honra, J. R. (2026). Understanding the influence of biomimetic projects on transdisciplinary thinking in biology education. *Innovations in Education and Teaching International*, 63(3), 766–780.
- Irabor, T.-J., Yameogo, P. S. A., Perrin, L., Pétré, B., Faulx, D., Ruëgg, S. R., & Antoine-Moussiaux, N. (2025). Gaming for change-exploring systems thinking and sustainable practices through complexity-inspired game mechanics. *Humanities and Social Sciences Communications*, 12(1), 680.
- Kang, J., Xu, X., & Yan, L. (2025). Leveraging affordances of immersive technology-supported collaborative learning (ITCL): A systematic review. *Education and Information Technologies*, 30(1), 607–647.
- Mafarja, N., Zulnadi, H., & Mohamad, M. M. (2026). Virtual learning environment to improve scientific literacy: a systematic review. *Research in Science & Technological Education*, 44(2), 736–760.
- Mayer, R. E. (2005). Cognitive theory of multimedia learning. *The Cambridge handbook of multimedia learning*, 41(1), 31–48.
- Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & education*, 70, 29–40.
- Mulders, M., Buchner, J., & Kerres, M. (2020). A framework for the use of immersive virtual reality in learning environments. *International Journal of Emerging Technologies in Learning (iJET)*, 15(24), 208–224.
- Noor, S. (2026). The Role of Virtual Reality in Transforming Education. *International journal of language, literature and social sciences review*, 3(1), 28–37.
- Okoye, P. O. (2016). Influence of gender and cognitive styles on students' achievement in Biology. *AFRREV STECH: An International Journal of Science and Technology*, 5(1), 59–65.

- Paivio, A. (2014). Intelligence, dual coding theory, and the brain. *Intelligence*, 47, 141–158.
- Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & education*, 147, 103778.
- Schwartz, E., & Blau, I. (2026). Not all immersive technologies are equal: Bridging teachers' instruction and students' perceived learning in immersive educational environments. *Education Sciences*, 16(2), 190.
- Sembiring, D. A. E. P., & Yusuf, M. (2025). How do students understand biological concepts? A study on science literacy in basic education. *Jurnal Sinar Edukasi| JSE*, 6(03), 207–222.
- Shirley, C., Jebadurai, I. J., Paulraj, G. J. L., & Princess, P. J. B. (2025). Principles and Applications of Virtual and Augmented Reality. *Virtual Reality and Augmented Reality with 6G Communication*, 21–49.
- Shutaleva, A. (2023). Ecological culture and critical thinking: building of a sustainable future. *Sustainability*, 15(18), 13492.
- Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, 34(9), 1337–1370.
- Usman, H. (2021). *Effects of Physical and Virtual Laboratories on Learning Outcomes in Geography among Senior Secondary School Students in North Central Nigeria*
- Zakariya, Y. F. (2022). Cronbach's alpha in mathematics education research: Its appropriateness, overuse, and alternatives in estimating scale reliability. *Frontiers in Psychology*, 13, 1074430. <https://doi.org/10.3389/fpsyg.2022.1074430>
- Zou, Y., Zhai, X., Cheng, S., & Gao, C. (2026). Examining the impact of virtual reality on middle school students' biology learning outcomes and experiences. *International Journal of Science Education*, 1–23.

Publisher's Note

The views, interpretations, and conclusions expressed in this article are solely those of the author(s) and do not necessarily reflect the views or policies of the Journal of Studies in Science and Mathematics Education (JOSSME), its publisher, editorial board, editors, reviewers, or the authors' affiliated institutions. The publisher remains neutral with respect to jurisdictional claims in published maps, institutional affiliations, and other representations. Any products, materials, methods, or manufacturers mentioned or evaluated in this article are presented solely for scholarly purposes and do not constitute endorsement, recommendation, or guarantee by the publisher.