

**Review Article**

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Virtual Reality and its Effectiveness in Science Learning: A Mini-Review

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***Corresponding author:** science Education Study Program, Universitas Pendidikan Indonesia, Bandung, Indonesia**Received Date:** June 02, 2026**Published Date:** June 09, 2026**Abstract**

The rapid advancement of Virtual Reality (VR) technology has introduced new possibilities for enhancing science education by providing immersive, interactive, and experiential learning environments. This mini-review examines empirical studies from 2015 to 2025 that evaluate the effectiveness of VR in science learning. VR offers immersive and interactive experiences, facilitating conceptual understanding, problem-solving skills, and practical competencies. Key characteristics of VR in science education include enhanced visualization of abstract concepts, experiential learning, and virtual laboratory simulations. The findings suggest that VR significantly improves student motivation, engagement, and retention. Furthermore, VR-based virtual field trips and first-person experiential simulations provide unique learning opportunities that traditional methods cannot offer. However, challenges such as high costs, technological accessibility, and teacher training remain barriers to its widespread adoption. Overall, VR has the potential to transform science education by bridging the gap between theoretical knowledge and practical experience, making learning more engaging, effective, and accessible.

Keywords: Educational technology; science education; simulation; virtual reality**Introduction**

The development of technology in education has brought significant changes in the way students understand and learn about science. One innovation that has been gaining increasing attention is the use of Virtual Reality (VR) in learning. VR allows students to experience a more interactive and immersive learning environment, which can impact their attitudes, motivation, conceptual understanding, and learning experiences [1-2]. Science education often involves visualizing abstract phenomena such as chemical reactions, planetary motion, or cell structures, and this technology can bridge the gap between theory and practice. With VR, students do not merely read or look at static images but can also interact directly with objects or simulations [3]. Although the

potential of VR in education is immense, its implementation still faces several challenges, such as high costs, the need for specialized devices, and teacher training to optimize its use in learning.

Virtual Reality in science education refers to the use of digital simulation technology that enables students to explore and interact with virtual environments. Several applications of VR in science education include virtual laboratory simulations [4], space exploration [5], and the reconstruction of the history of biological evolution [6]. For instances, by using VR, students can conduct virtual chemistry experiments without the risk of accidents or material limitations. VR-based learning can enhance conceptual understanding, problem-solving skills, and students' memory

retention [7]. Therefore, this study aims to examine the effectiveness of VR in science education by highlighting the characteristics of the subject matter and its benefits in increasing student engagement, as well as the future prospects of VR technology. By understanding various aspects of VR implementation in science learning, it is hoped that VR innovations can be more widely and effectively integrated into the education system.

Method

This mini-review method follows a systematic approach to identify, analyze, and synthesize empirical studies that evaluate science learning outcomes using VR within the timeframe of 2015–2025. The literature search was conducted through the Scopus and Web of Science (Woos) databases, both of which provide extensive coverage of high-impact scientific publications (Singh, 2021). The keywords used in the search focused on immersive technology concepts in science education, utilizing the combination: TITLE-ABS-KEY: (“virtual reality” OR “VR” OR “immersive technology” OR “simulated environment”) AND (“science education” OR “science learning” OR “science teaching” OR “STEM education”) AND (“simulation” OR “modeling” OR “visualization” OR “experiential learning”). The included articles were published in English, conducted within the field of science learning, and featured empirical research designs involving VR. Conceptual or theoretical review articles were excluded. Studies that met the criteria were analyzed based on the objectives of this mini-review.

Characteristics of Virtual Reality as a Learning Tool in Science Education

VR-based science learning possesses key characteristics that distinguish it from conventional methods, namely immersive Ness, interactivity, simulation, and direct experiential learning. VR technology creates an immersive and interactive learning environment, enabling students to actively engage with scientific concepts. Furthermore, VR offers virtual simulations and experiments, allowing students to conduct complex or hazardous experiments that would be difficult or unsafe in real-world settings. As a result, VR-based learning provides a deeper and more impactful educational experience. Each of these characteristics is outlined and discussed below.

Immersion and interactivity in science concept exploration

VR-based science learning enables students to experience full immersion in an interactive virtual environment [8]. Through this technology, students can visually explore abstract concepts and directly interact with scientific objects or phenomena that are otherwise difficult to access in the real world. For instance, students can “walk” inside an atom or observe planetary motion in the solar system in real time. This interactivity enhances conceptual understanding, making learning more engaging and profound.

Simulation and virtual experiments

VR enables students to conduct scientific simulations and

experiments without the risks or limitations of traditional laboratory equipment [3]. They can perform physics, chemistry, or biology experiments with precise results that can be repeated at any time. This is particularly beneficial for understanding complex scientific concepts, such as hazardous chemical reactions or stellar evolution. In this way, VR enriches the learning experience and provides significant cognitive benefits for students.

Experience-Based learning

VR creates a learning experience that allows students to feel as if they are in a real environment [9]. For instances, students can dive to the ocean floor to study ecosystems or explore the human body at a microscopic scale. This immersive experience enhances students’ understanding of the material, as they do not merely read or listen to explanations but actively engage with the content in a virtual setting.

Effectiveness of Virtual Reality in Science Education

Immersive visualization of abstract scientific concepts

Scientific concepts are often inherently abstract, characterized by phenomena that cannot be directly observed and scales that are either extremely large or minuscule, posing significant challenges to comprehension [10]. For instance, in the fields of biology and chemistry, virtual reality (VR) has been employed to enlarge microscopic three-dimensional structures, such as cellular organelles and their functions [11-12] as well as molecular configurations and interactions [13-14]. Similarly, in physics and astronomy, VR technology has facilitated the visualization of complex theories, including the special theory of relativity [15], thermodynamic principles such as heat and temperature [16], and the scaling down of vast celestial bodies, such as planets within the solar system [17].

Improving learning experience

Research examining the design and implementation of VR applications has sought to evaluate the broader educational efficacy of this emerging technology in science instruction. Researchers have utilized VR to enhance student engagement [18] foster greater motivation in science learning [19]. To sustain learner immersion, some educational VR applications incorporate gamification elements, such as reward systems, structured rules, and real-time feedback mechanisms [20].

Practical skills building

The development of scientific competence necessitates hands-on laboratory experience, enabling learners to cultivate skills in observation, prediction, and inference-making about natural phenomena. To facilitate this process, science educators have implemented virtual reality (VR) laboratory simulations, which allow students to safely practice experimental procedures using virtual equipment [21] and handle hazardous chemical substances [22-23]. These immersive VR experiences were designed to enhance students’ proficiency with standard laboratory protocols through repeated virtual practice.

Virtual field trips

Numerous scientific concepts in disciplines like geology and environmental science necessitate field-based learning; however, conventional field excursions often impose significant logistical and financial burdens [24]. To address these constraints, specialized VR applications have been developed to virtually transport students to pertinent field locations. For instances, Jong et al. [25] implemented VR to enable geological investigations of coastal formations through immersive simulations. Similarly, researchers have utilized VR to facilitate observations of remote environmental phenomena [26-27]. VR allowed learners to conveniently visit and explore relevant but hard-to-reach sites.

Supports experiential learning opportunities

Certain scientific concepts often seem abstract or remote to learners, presenting significant pedagogical challenges [28]. To address this, researchers have employed virtual reality (VR) to create immersive, first-person learning experiences. These VR environments enable students to develop empathy and alter their perspectives regarding societal and ecological concerns that would otherwise be difficult to encounter directly [29-30]. For instances, rather than simply showing a video about the impact of climate change on marine ecosystems. Markowitz et al. [28] developed a VR application that allows learners to experience being a fish living in an increasingly acidic environment due to increased CO₂ levels. In this simulation, learners experience difficulty finding food and avoiding predators due to sensory impairment caused by ocean acidification. As such, VR changes learners' perspective from an external observer (as when watching a video on a 2D screen) to a first-person perspective, creating the psychological illusion that they are actually experiencing the impacts of climate change first-person.

Conclusion

While VR in science education has shown promising results, several limitations need to be addressed. The high cost of VR equipment and software restricts accessibility, particularly in underfunded educational institutions, while technical challenges such as motion sickness and hardware limitations can affect the user experience. Additionally, the lack of standardized pedagogical frameworks hinders the effective integration of VR into science curricula, and most studies focus on short-term learning outcomes without assessing long-term knowledge retention and transferability. Future research should explore cost-effective VR solutions, investigate strategies to mitigate technical barriers, and develop instructional design models tailored for VR-based science learning. Longitudinal studies are also needed to assess the sustained impact of VR on student learning and its potential influence on career pathways in STEM fields. Despite these challenges, VR presents a transformative approach to science education by bridging the gap between theoretical knowledge and hands-on experiences. By enhancing conceptual understanding, engagement, and practical skills development, VR offers an innovative way to teach complex scientific phenomena. Addressing

current limitations and advancing research in this area will ensure that VR continues to play a significant role in shaping the future of science education, making learning more immersive, effective, and accessible.

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