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The Use of Virtual Reality to Support Science and Mathematics Learning in Secondary Schools

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Abstract: Science and mathematics education at the secondary school level faces challenges in conveying abstract concepts that require high levels of visualization and cognitive understanding. Virtual Reality (VR) is an emerging educational technology that has the potential to enhance learning through immersive and interactive experiences. This study aims to investigate the use of VR in supporting science and mathematics education at the secondary level through a qualitative analysis of relevant literature A qualitative approach with document analysis was employed, reviewing academic journals, conference proceedings, theses, and instructional documents related to VR in education. Data were analyzed descriptively to identify the role of VR in facilitating conceptual understanding and student engagement. The findings indicate that VR can enhance visualization of abstract concepts, increase learning engagement, and enrich students' learning experiences. Therefore, VR has the potential to serve as an effective educational tool for science and mathematics if implemented systematically and sustainably.

Keywords: virtual reality, science education, mathematics education, qualitative study, secondary school

Introduction

Science and mathematics are foundational disciplines within secondary education, serving not only as vehicles for the transmission of scientific and numerical knowledge but also as essential instruments for cultivating students' logical reasoning, analytical abilities, problem-solving competence, and critical thinking skills (Goos et al., 2023; Just & Siller, 2022; Kaur et al., 2022; Rohman, Isnaeni, et al., 2025). Mastery of these subjects is increasingly important in the context of rapid scientific and technological advancement, as it prepares learners to engage with complex real-world problems and to participate effectively in knowledge-based societies. Despite their importance, science and mathematics are frequently perceived by secondary school students as difficult and abstract, particularly when concepts involve microscopic structures, multidimensional relationships, dynamic processes, or theoretical models that are not directly observable in everyday experiences (Henukh et al., 2024; Syahdah & Irvani, 2023; Utha et al., 2023; Wen & Dubé, 2022).

Traditional instructional approaches in science and mathematics classrooms often rely heavily on textbooks, static images, symbolic representations, and two-dimensional visualizations (Warliani et al., 2025; Ziatdinov & Valles Jr, 2022). While these methods may be sufficient for conveying basic

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information, they often fall short in facilitating deep conceptual understanding and meaningful learning, especially for learners who require concrete representations and experiential engagement. As a result, students may struggle to construct accurate mental models of complex phenomena, which can lead to misconceptions, reduced motivation, low engagement, and ultimately suboptimal academic achievement (Biber, 2023; Pelani et al., 2025; Sharma, 2025). These challenges highlight the need for more innovative, student-centered instructional strategies that can bridge the gap between abstract theory and tangible understanding.

The rapid development of digital technologies in education offers promising opportunities to address these pedagogical limitations. Among emerging educational technologies, Virtual Reality (VR) has gained increasing attention due to its capacity to create immersive, interactive, and three-dimensional learning environments (Paling et al., 2024; Yang, 2023; Ye et al., 2024). VR allows learners to explore virtual spaces, manipulate objects, and observe processes that would otherwise be inaccessible, dangerous, costly, or impossible to experience directly in conventional classroom settings (Childs et al., 2023; Henukh, Irvani, Yuliatun, et al., 2025; Hite, 2022). In the context of science and mathematics education, VR has the potential to transform abstract concepts into experiential learning opportunities by enabling students to visualize mathematical structures, simulate scientific experiments, and interact with complex systems in real time.

Empirical studies have suggested that the integration of VR into educational practices can enhance student engagement, motivation, and conceptual understanding, particularly in subjects that demand spatial reasoning and visualization (Chasokela, 2025; Serrano-Ausejo & Mårell-Olsson, 2024; Sholihin & Irvani, 2025). Learners exposed to VR-based instruction often demonstrate increased curiosity and active participation, as the immersive nature of the technology encourages exploration and experiential learning (Chasokela, 2025; Heryanto et al., 2023; Serrano-Ausejo & Mårell-Olsson, 2024). However, much of the existing research in this area has predominantly employed quantitative methods focusing on learning outcomes, test scores, or comparative effectiveness, while qualitative investigations that explore students' perceptions, learning experiences, and cognitive processes remain relatively scarce.

Moreover, studies that specifically examine the role of VR in supporting science and mathematics learning at the secondary school level are still limited, particularly in terms of understanding how VR influences students' conceptual comprehension, engagement, and learning interactions within classroom contexts. Addressing this research gap is crucial for informing educators and policymakers about the pedagogical value and practical implications of integrating VR into secondary education. Therefore, this study aims to explore the use of Virtual Reality as an instructional tool in science and mathematics learning at the secondary school level, with a particular focus on examining its potential to support conceptual understanding, enhance student engagement, and enrich the overall learning experience.

Method

This study adopts a qualitative research approach employing a descriptive–analytical design to obtain an in-depth and comprehensive understanding of the use of Virtual Reality (VR) in science and mathematics education at the secondary school level through systematic document analysis. A qualitative approach is considered particularly appropriate for this study, as the research seeks to interpret patterns, meanings, and pedagogical implications derived from documented implementations of VR rather than to measure learning outcomes through numerical indicators (Masripah et al., 2024; Tintori et al., 2021). Qualitative research enables the exploration of contextualized educational phenomena and allows researchers to capture nuanced insights into how instructional technologies are conceptualized, implemented, and experienced within educational settings (Amarulloh & Irvani, 2025; Creswell & Creswell, 2017).

The primary data sources for this study consist of a wide range of academic and instructional documents, including peer-reviewed journal articles, conference proceedings, master's theses, doctoral dissertations, policy reports, and instructional design documents that explicitly report the application of VR in secondary school science and mathematics learning contexts. To ensure the relevance and credibility of the data, purposive sampling was employed, whereby documents were selected based on predefined criteria, including alignment with the research objectives, methodological rigor, academic credibility, and the explicit discussion of VR-based learning applications. This sampling strategy allows for the intentional selection of information-rich sources that can provide deep insights into the phenomenon under investigation, as recommended in qualitative research methodology literature (Creswell & Creswell, 2017).

Data collection involved a systematic and iterative literature search across multiple academic databases and digital repositories, such as indexed journal platforms and institutional repositories (Henukh et al., 2025; Zibani et al., 2022). The selected documents were subjected to comprehensive and repeated readings to extract relevant information related to VR implementation, particularly focusing on aspects of concept visualization, immersive learning experiences, student engagement, and instructional design strategies. Extracted data were systematically recorded, coded, and categorized into thematic units to facilitate detailed qualitative analysis and cross-source comparison.

Data analysis was conducted using qualitative descriptive analysis, which included stages of data reduction, thematic categorization, data display, and conclusion drawing. This process enabled the identification of recurring patterns, emerging themes, and conceptual relationships related to the pedagogical role of VR in science and mathematics education. To enhance the trustworthiness of the findings, triangulation was applied by comparing data across multiple types of documents and sources, thereby increasing the validity and reliability of the interpretations (Creswell & Creswell, 2017). Through this analytical process, the study synthesizes current evidence regarding best practices, pedagogical benefits, challenges, and limitations associated with VR-based learning environments.

Special attention was given to identifying dominant trends reported in the literature, particularly in relation to immersive visualization, interactivity, spatial cognition, and cognitive engagement. Additionally, the analysis considered broader contextual factors such as technological readiness, accessibility and affordability of VR resources, teacher competencies, and institutional support for technology integration. Integration strategies and implementation frameworks recommended by previous researchers were also examined to provide practical implications for educators and policymakers. By adopting this comprehensive and systematic methodological approach, the study ensures that its conclusions are grounded in diverse, high-quality sources and offer both theoretical contributions and practical insights into the effective integration of Virtual Reality to support science and mathematics learning at the secondary school level.

Result and Discussion

The document analysis reveals that Virtual Reality (VR) plays a significant role in facilitating students' understanding of complex and abstract concepts in science and mathematics at the secondary school level. Across the reviewed literature, VR consistently emerges as an effective pedagogical medium due to its capacity to provide interactive, three-dimensional, and immersive visualizations that enable learners to actively construct conceptual understanding through experiential engagement. Unlike conventional two-dimensional instructional media, VR allows students to interact directly with learning content, thereby supporting deeper cognitive processing and meaningful learning, as emphasized in constructivist learning theory (Pandeka et al., 2021; Sandu et al., 2019; Sari et al., 2025).

In the context of science education, VR is widely utilized to visualize scientific phenomena and processes that are inherently difficult, impractical, or impossible to observe directly in real-world classroom settings. These include microscopic structures such as molecular interactions, cellular processes, and chemical reactions, as well as macroscopic systems such as the solar system, geological formations, and ecological processes. Immersive VR environments enable students to explore these phenomena from multiple perspectives, manipulate variables, and observe dynamic changes over time. Such experiences foster integrative understanding by allowing learners to perceive relationships among scientific concepts that are often fragmented when presented through static images or verbal explanations alone. This finding supports previous research indicating that immersive visualization can reduce cognitive load and enhance conceptual coherence in science learning (Liu et al., 2022; Rohman, Irvani, et al., 2025; Wenk et al., 2023).

Furthermore, VR-based science learning environments encourage inquiry-based and exploratory learning, where students actively investigate phenomena rather than passively receive information. This interactive engagement has been shown to increase learners' curiosity, intrinsic motivation, and sustained attention, which are critical factors for effective science learning. As a result, VR demonstrates strong potential as an instructional media tool capable of enriching science content delivery and supporting higher-order thinking skills, including analysis, synthesis, and scientific reasoning.

In mathematics education, the findings indicate that VR is particularly effective in supporting students' understanding of geometric and spatial concepts, which are often perceived as abstract and cognitively demanding. Three-dimensional representations of geometric objects, transformations, and spatial relationships allow students to visualize and manipulate mathematical constructs in ways that are not possible through traditional diagrams or symbolic representations. Through VR, abstract mathematical ideas are transformed into tangible learning experiences, enabling students to develop clearer mental models and stronger conceptual understanding. This aligns with spatial cognition theory, which emphasizes the importance of visual-spatial representations in mathematical reasoning and problem-solving (Duffy et al., 2024; Zolfaghari et al., 2026).

The literature further suggests that VR-based mathematics learning promotes the development of spatial reasoning skills, such as mental rotation, spatial visualization, and spatial orientation, which are essential for success not only in geometry but also in advanced mathematics and STEM-related fields. By engaging students in immersive spatial exploration, VR supports deeper conceptual learning and helps bridge the gap between abstract mathematical theory and concrete understanding.

Despite the predominantly positive outcomes reported in the literature, several challenges related to VR implementation were consistently identified. These challenges include limited access to VR hardware, high costs associated with equipment and software development, technical constraints, and varying levels of teacher readiness and technological competence. The effectiveness of VR integration is highly dependent on thoughtful instructional design and alignment with clearly defined learning objectives. Without pedagogically sound planning, VR risks being used merely as a novelty rather than as a meaningful learning tool. As highlighted by Koehler and Mishra (2009), successful technology integration requires the intersection of technological knowledge, pedagogical knowledge, and content knowledge.

Consequently, the literature emphasizes the need for supportive educational policies, institutional commitment, and continuous professional development programs to enhance teachers' capacity to integrate VR effectively into classroom instruction. Teacher training should focus not only on technical operation but also on pedagogical strategies for facilitating immersive, student-centered learning experiences. Additionally, issues of accessibility and equity must be addressed to ensure that the benefits of VR-enhanced learning are available to diverse student populations.

Overall, the synthesis of existing literature demonstrates that VR has considerable potential to transform science and mathematics education by enhancing student engagement, motivation, and conceptual understanding. When implemented strategically and systematically, VR can provide interactive, learner-centered experiences that extend beyond the capabilities of traditional instructional methods. These findings suggest that VR should be viewed not as a replacement for conventional teaching approaches, but as a complementary pedagogical tool that, when aligned with sound instructional design and supported by institutional structures, can significantly enrich secondary school science and mathematics learning.

Conclusion

This qualitative document analysis concludes that Virtual Reality (VR) demonstrates substantial potential as an innovative pedagogical tool in secondary school science and mathematics education. The synthesis of existing literature indicates that VR effectively supports the visualization of complex and abstract concepts that are often difficult to comprehend through conventional instructional media. By providing immersive, interactive, and three-dimensional learning environments, VR enriches students' learning experiences and fosters higher levels of engagement, motivation, and conceptual understanding. These affordances position VR as a valuable complement to traditional teaching approaches, particularly in content areas that require strong spatial reasoning and conceptual integration.

Nevertheless, the effectiveness of VR integration is not determined solely by the technology itself but is highly dependent on contextual and pedagogical factors. Key challenges identified include limited access to technological resources, high implementation costs, disparities in infrastructure, and variations in teachers' technological and pedagogical competencies. Furthermore, the literature underscores the importance of systematic instructional planning to ensure that VR-based activities are meaningfully aligned with learning objectives, curriculum standards, and students' cognitive needs. Without careful pedagogical design, the educational potential of VR may remain underutilized.

Therefore, the integration of VR into secondary school curricula should be approached strategically and sustainably. This requires supportive institutional policies, adequate infrastructure, and continuous professional development programs that equip teachers with the skills necessary to design and facilitate effective VR-enhanced learning experiences. Future research is also recommended to explore longitudinal impacts, classroom implementation models, and qualitative insights into students' learning processes to further inform evidence-based practices. Overall, when thoughtfully designed and systematically implemented, Virtual Reality has the capacity to significantly enhance science and mathematics education and contribute to more engaging, student-centered learning environments.

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Conflicts of Interest
The author declares no conflict of interest in the research and publication of this article.

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