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Virtual Reality in Science Education: A Systematic Literature Review on Students' Learning Motivation

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ABSTRACT

The growing use of Virtual Reality (VR) in science education has attracted considerable attention due to its potential to create immersive, interactive learning experiences. However, previous studies have mainly focused on cognitive outcomes, while research specifically examining students' learning motivation remains fragmented. Therefore, this study aims to analyze publication trends, country contributions, mapping of academic fields, and the implementation of VR in science education related to students' learning motivation. This study employed a Systematic Literature Review (SLR) approach following the PRISMA 2020 guidelines. Data were collected from the Scopus database using Publish or Perish 8, covering publications from 2016 to 2026, and 25 selected articles were analyzed qualitatively. The findings indicate that research on VR in science education has increased significantly, particularly after 2020, with the United States, Taiwan, Spain, and China as the major contributors. The studies were dominated by Computer Science and Social Sciences, reflecting the interdisciplinary nature of VR research. Furthermore, VR was found to enhance students' learning motivation through immersive experiences, interactivity, engagement, and contextual visualization. However, excessive immersion may increase cognitive load if not supported by appropriate instructional design. Therefore, VR should be integrated with appropriate pedagogical strategies to create more engaging, student-centered science learning environments.

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1. INTRODUCTION

Advances in digital technology have significantly transformed the educational landscape, particularly in enabling more interactive, student-centered learning environments. One emerging technology that has gained considerable attention is Virtual Reality (VR), which enables learners to experience immersive, interactive three-dimensional environments. VR allows students to explore complex concepts through simulation and

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visualization, offering learning experiences that are difficult to achieve through conventional instructional methods [1], [2], [3], [4].

In the context of science education, the use of VR is increasingly relevant due to the abstract and complex nature of many scientific concepts, such as microscopic processes, dynamic systems, and phenomena that cannot be directly observed. Traditional teaching methods often fail to provide concrete representations of these concepts, hindering students' understanding. Therefore, innovative learning tools that can visualize abstract concepts more tangibly and interactively are needed. VR offers a promising solution by integrating visualization, interactivity, and simulation-based learning experiences [5], [6].

However, learning success is not solely determined by the use of instructional media, but also by internal factors within the learner, particularly learning motivation. Learning motivation plays a crucial role in determining students' engagement, persistence, and overall learning outcomes [7], [8]. Students with high levels of motivation tend to be more active, engaged, and willing to explore learning materials in greater depth, whereas low motivation may lead to passive learning behaviors and reduced participation [3], [9].

Learning motivation can be explained through several theoretical perspectives, such as the ARCS model (Attention, Relevance, Confidence, Satisfaction), which emphasizes motivational design in instructional environments, and Self-Determination Theory, which highlights the importance of intrinsic motivation, autonomy, and learner engagement. In this regard, VR has the potential to support these motivational components by providing immersive experiences, increasing curiosity, and promoting active participation in the learning process [10], [11].

Several previous studies have reported that Virtual Reality can enhance students' engagement, interest, and learning outcomes in science education [2], [11], [12]. In addition, VR has been shown to support experiential learning and improve students' understanding of abstract scientific concepts [5], [6]. However, most of these studies emphasize cognitive aspects, while the role of learning motivation is often treated as a secondary outcome rather than a primary focus. Moreover, variations in research contexts, instructional approaches, and subject areas have led to inconsistent findings, making it difficult to generalize the effectiveness of VR in enhancing students' motivation.

Although numerous studies have explored the use of Virtual Reality in education, most focus primarily on cognitive outcomes such as conceptual understanding and academic achievement. Studies that specifically examine learning motivation as a central variable remain limited. Furthermore, existing findings are scattered across different educational contexts, learning models, and subject areas, resulting in a lack of comprehensive synthesis. This fragmentation makes it difficult to draw a clear conclusion regarding how Virtual Reality contributes to students' learning motivation in science education.

To address these limitations, this study adopts a Systematic Literature Review (SLR) approach to systematically identify, evaluate, and synthesize relevant studies on the use of Virtual Reality in science education. Through this approach, the study aims to provide a comprehensive and structured understanding of how VR contributes to students' learning motivation.

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The findings of this study are expected to contribute both theoretically and practically. Theoretically, this study provides a comprehensive synthesis of existing research on Virtual Reality and learning motivation, thereby enriching the literature in science education. Practically, the results can serve as a reference for educators and researchers in designing more effective VR-based learning environments that enhance students' motivation.

Therefore, this study aims to analyze publication trends, country contributions, mapping of academic fields, and the implementation of Virtual Reality in science education with respect to learning motivation.

Based on this background, this study addresses the following research questions: (1) What are the trends in publications regarding the use of Virtual Reality in science education in Scopus-indexed articles from 2016 to 2026? (2) Which countries have contributed the most to research on Virtual Reality in science education? (3) How do scientific disciplines map research in studies of Virtual Reality in science education? (4) How is Virtual Reality implemented in science education, and how does it contribute to enhancing students' learning motivation?

2. METHOD

This study employed a Systematic Literature Review (SLR) approach to analyze previous research on the use of Virtual Reality (VR) in science education and its relationship to students' learning motivation. The SLR method was chosen because it provides a systematic and transparent process for identifying, evaluating, and synthesizing relevant studies. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [15].

2.1 Data Source and Search Strategy

The data were collected from the Scopus database, which is widely recognized for indexing high-quality international publications. The search was conducted on March 18, 2026, covering publications from 2016 to 2026 using Publish or Perish 8. The search query used Boolean operators as follows: ("virtual reality" OR VR OR "immersive learning") AND ("science education" OR "science learning" OR biology OR chemistry OR physics) AND ("project-based learning" OR PjBL) AND ("learning motivation" OR motivation). This strategy ensured that the retrieved studies were relevant to VR implementation in science education and learning motivation.

2.2 Study Selection Process

The study selection process followed four stages based on PRISMA: identification, screening, eligibility, and inclusion. The detailed process is illustrated in Figure 1.

In the identification stage, 200 articles were initially identified through database searching. No additional records were obtained from other sources. After removing duplicates, 185 articles remained. In the screening stage, titles and abstracts were reviewed, resulting in the exclusion of 65 articles for irrelevance. In the eligibility stage, 120 full-text articles were assessed, and 95 were excluded for failing to meet inclusion criteria, such as

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irrelevance to learning motivation, unclear methodology, or incomplete data. In the inclusion stage, 25 articles met all criteria and were included in the qualitative synthesis.

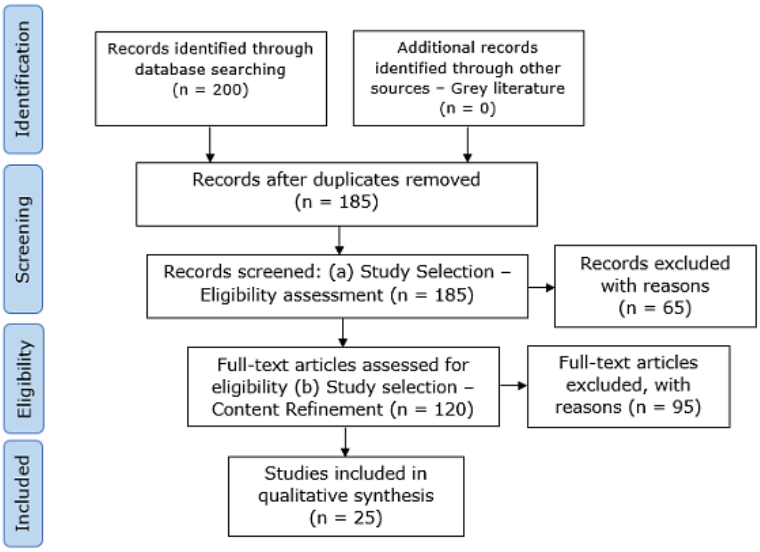

Figure 1. Literature Search Flowchart using PRISMA

2.3 Inclusion and Exclusion Criteria

The selection of articles was based on predefined inclusion and exclusion criteria, including research topic, publication period (2016–2026), publication type (peer-reviewed journal articles), language (English or Indonesian), research design, and availability of full text, as presented in Table 1.

Table 1. Inclusion and Exclusion Criteria of the Study

Criteria	Inclusion Criteria	Exclusion Criteria
Research topic	The article discusses the use of Virtual Reality in science education and its relationship to student motivation.	The article does not discuss Virtual Reality, is not related to science education, or is not related to learning motivation.
Publication period	Articles were published between 2016 and 2026 to ensure the research is up to date.	Articles published before 2016
Type of publication	Articles in reputable scientific journals (Scopus-indexed) and peer-reviewed	Conference proceedings, undergraduate theses, master's theses, doctoral dissertations, books, or non-peer-reviewed publications
Language	The article is written in English or Indonesian	Articles in other languages that may lead to interpretive bias
Research design	Empirical research with a clear methodology and measurable results	Conceptual articles, opinion pieces, or research studies with unclear methodologies
Availability	The article is available in full text and can be accessed in its entirety	Articles for which the full text is not available or the data is incomplete

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2.4 Quality Appraisal

A quality appraisal was conducted to ensure the reliability and methodological rigor of the selected studies. The appraisal process was adapted from the Critical Appraisal Skills Programme (CASP) framework. Each article was evaluated based on five criteria: clarity of objectives, appropriateness of research design, transparency of data collection, validity of data analysis, and relevance to the research topic.

Each criterion was scored on a scale of 0–1 (1 = yes, 0.5 = partially, 0 = no), resulting in a maximum score of 5 for each study. Studies with scores below 3 were excluded from the review. The results of the quality appraisal are presented in Table 2. Overall, the selected studies achieved scores of 4 to 5, indicating high methodological quality and ensuring the credibility of the synthesized findings.

Table 2. Quality Appraisal of Selected Study

No.	Author (Year)	Q1 Objective	Q2 Design	Q3 Data	Q4 Analysis	Q5 Relevance	Score	Category
1.	Gao et al. (2019)	1	1	1	1	1	5	High
2.	Makransky et al. (2019)	1	1	1	1	1	5	High
3.	Yang et al. (2024)	1	1	1	1	1	5	High
4.	Reen et al. (2022)	1	1	1	1	1	5	High
5.	Maulana & Purnomo (2021)	1	1	1	0.5	1	4.5	High
6.	Kolodner et al. (2017)	1	0.5	1	0.5	1	4	High
7.	Liu et al. (2020)	1	1	1	1	1	5	High
8.	Chang et al. (2019)	1	1	1	1	1	5	High
9.	Liu et al. (2025)	1	1	0.5	1	1	4.5	High
10.	Arayaphan et al. (2022)	1	1	1	1	1	5	High
11.	Lindgren et al. (2016)	1	1	1	1	1	5	High
12.	Makransky et al. (2019)	1	1	1	1	1	5	High
13.	Jong (2022)	1	1	0.5	1	1	4.5	High
14.	Zhang et al. (2020)	1	1	1	1	1	5	High
15.	Huang et al. (2021)	1	1	1	1	1	5	High
16.	Cheng & Tsai (2020)	1	1	1	1	1	5	High
17.	Andreasen et al. (2019)	1	1	1	1	1	5	High
18.	Parong & Mayer (2020)	1	1	1	1	1	5	High
19.	Cho & Park (2023)	1	1	1	1	1	5	High
20.	Tsirulnikov et al. (2023)	1	1	1	1	1	5	High
21.	Yang et al. (2024)	1	1	1	1	1	5	High

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No.	Author (Year)	Q1 Objective	Q2 Design	Q3 Data	Q4 Analysis	Q5 Relevance	Score	Category
22.	Abdelaziz et al. (2020)	1	1	1	1	1	5	High
23.	Wang et al. (2024)	1	1	1	1	1	5	High
24.	Zhong & Liu (2022)	1	1	1	1	1	5	High
25.	Ferrer et al. (2017)	1	0.5	1	0.5	1	4	High

Based on Table 2, all selected studies achieved scores of 4-5, indicating high methodological quality. Most studies fulfilled all appraisal criteria, particularly in terms of research objectives, research design, and relevance to the research topic. A few studies received slightly lower scores due to limited explanation of data analysis procedures or research design details. Nevertheless, all included articles met the minimum quality threshold and were considered suitable for qualitative synthesis.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Trends in Virtual Reality Publications in Science Education

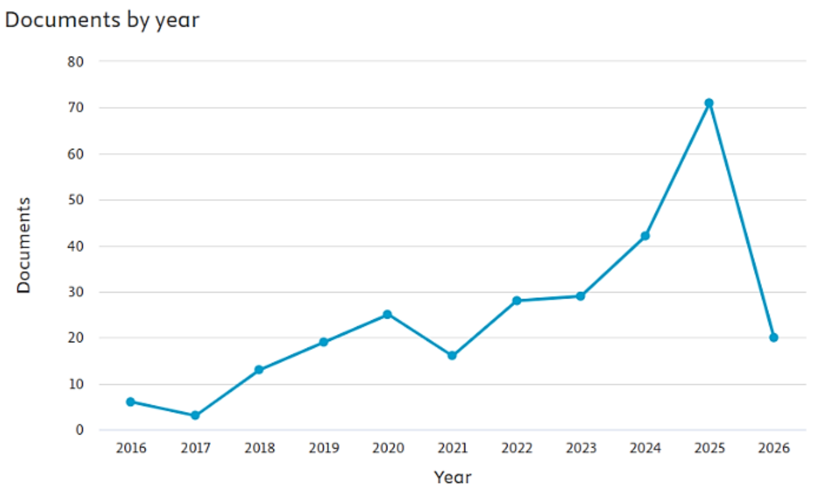

Figure 2. Trends in Virtual Reality Publications in Science Education from 2016 to 2026

Based on a Scopus analysis, 272 documents on the use of Virtual Reality in science education were identified for the period 2016–2026. The publication trend shows a significant increase over the past decade. In 2016 and 2017, the number of publications remained relatively low, at approximately 6 and 3 articles, respectively. However, from 2018 to 2020, there was a gradual increase, reaching 25 articles in 2020. Subsequently, the number of publications continued to rise sharply from 2022 to 2025, peaking at 71 articles in 2025.

This trend indicates growing research interest in integrating Virtual Reality in science education. The rapid growth after 2020 can be attributed to the acceleration of digital transformation in education, particularly the global shift toward technology-enhanced learning environments. In addition, advancements in VR technology, including improved

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accessibility and affordability of VR devices, have contributed to the expansion of research in this field. These findings suggest that VR is evolving from an emerging technology into a significant research area in science education.

The sharp increase in publications after 2020 may also reflect the educational impact of the COVID-19 pandemic, which accelerated the adoption of digital and immersive learning technologies worldwide. During this period, educators increasingly sought alternative learning approaches to support remote and interactive learning environments. As a result, VR became more widely explored not only as a technological innovation but also as a pedagogical tool to improve student engagement and motivation in science learning. This trend suggests that VR research is increasingly driven by educational needs rather than solely by technological advancement.

3.1.2. Countries' Contributions to Publications

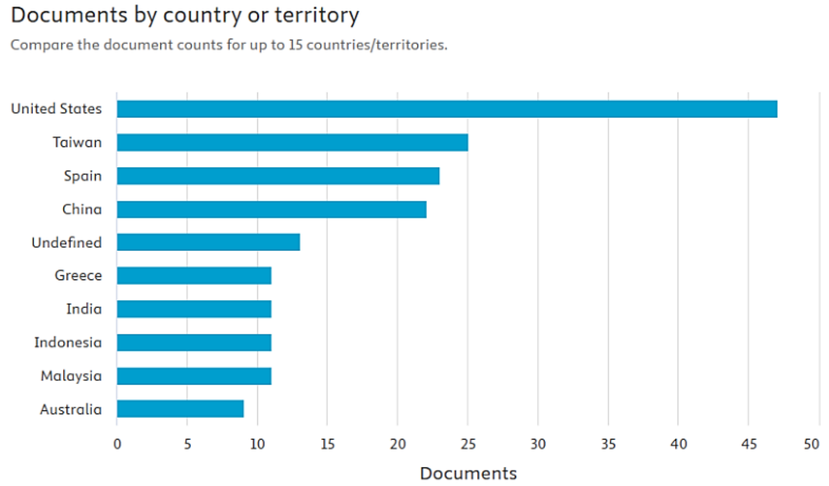

Figure 3. Countries' Contributions to Virtual Reality Publications in Science Education

The analysis shows that a few countries dominate research on Virtual Reality in science education. The United States ranks highest with 47 publications, followed by Taiwan (25), Spain (23), and China (22). Other countries, such as Greece, India, Indonesia, and Malaysia, contributed approximately 11 publications each.

This distribution indicates that the availability of technological infrastructure, research funding, and access to VR devices strongly influences research productivity. Developed countries tend to lead in VR research due to their stronger technological ecosystems and investment in educational innovation. However, the presence of developing countries among the contributors suggests that VR research is becoming more globally distributed. This trend reflects the growing recognition of VR as a valuable tool for enhancing science learning, particularly in contexts where visualizing abstract concepts is essential.

The dominance of developed countries also indicates a potential research gap between technologically advanced and developing regions. Since VR implementation requires substantial technological infrastructure and financial investment, unequal access to VR devices may limit research productivity in developing countries. Consequently, current

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findings may be influenced by technological and socioeconomic disparities, potentially affecting the generalizability of VR implementation across different educational contexts.

3.1.3. Mapping of Academic Field

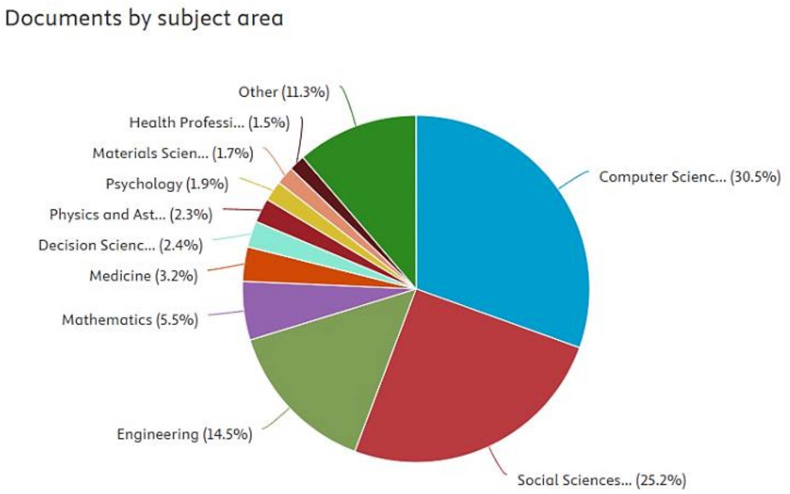

Figure 4. Mapping of the Academic Fields of Virtual Reality Publications in Science Education

Based on the analysis of subject areas in the Scopus database, research on Virtual Reality in education is dominated by Computer Science (30.5%), followed by Social Sciences (25.2%) and Engineering (14.5%).

The dominance of Computer Science suggests that VR research remains largely focused on technological development, such as system design and simulation environments. However, the significant contribution from Social Sciences suggests a shift toward pedagogical and psychological aspects of learning. This indicates that VR is no longer viewed solely as a technological tool, but also as a learning medium that influences student engagement and motivation. The presence of Engineering further highlights the role of hardware and system integration in supporting VR-based learning. Overall, this mapping reflects an interdisciplinary trend: effective VR implementation requires integrating technology and pedagogy.

The interdisciplinary nature of VR research indicates that effective VR implementation in education cannot rely solely on technological innovation. Instead, successful VR-based learning requires integrating educational theories, instructional design, and learner psychology. This shift toward interdisciplinary collaboration reflects the growing recognition that student engagement and motivation are central factors in determining the effectiveness of immersive learning environments.

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3.1.4 The Implementation of Virtual Reality and Its Impact on Learning Motivation

Table 2. Results of the Synthesis of Articles on the Implementation of Virtual Reality in Science Education and Findings Related to Learning Motivation

No.	Author (Year)	Key Findings	Relevance to the Study
1.	Gao et al. (2019)	VR-based educational games boost engagement and motivation through immersion and interactivity [16]	Shows that VR design influences students' motivation to learn
2.	Makransky et al. (2019)	VR enhances the sense of presence but can increase cognitive load and reduce learning outcomes [17]	This shows that VR does not always have a positive impact on motivation and learning outcomes.
3.	Yang et al. (2024)	SVVR improves motivation, learning attitudes, and understanding of chemistry concepts [6]	Relevant to science education and the visualization of abstract concepts
4.	Reen et al. (2022)	VR enhances understanding, engagement, and motivation in molecular biology education [12]	Supporting the use of VR in abstract science materials
5.	Maulana & Purnomo (2021)	VR boosts motivation through 3D visualization and interactive learning [1]	Demonstrating the role of VR as an interactive learning tool
6.	Kolodner et al. (2017)	VR boosts interest in and engagement with science [18]	Demonstrates improved attitude and motivation toward learning science
7.	Liu et al. (2020)	VR enhances engagement, learning outcomes, and acceptance of technology [19]	Engagement as an indicator of learning motivation
8.	Chang et al. (2019)	VR enhances motivation and learning outcomes in geology education [20]	Supporting the implementation of VR in science
9.	Liu et al. (2025)	VR boosts learning motivation and reduces cognitive load [21]	Demonstrating the effectiveness of VR in science education
10.	Arayaphan et al. (2022)	VR enhances intrinsic motivation but does not always lead to significant improvements in learning outcomes [9]	Highlighting the difference between motivation and learning outcomes
11.	Lindgren et al. (2016)	VR boosts engagement and fosters a positive attitude toward science [22]	Supporting experience-based motivation
12.	Makransky et al. (2019)	VR simulations yield comparable levels of motivation and learning outcomes between classroom and home learning [23]	Demonstrating the flexibility of VR in education
13.	Jong (2022)	VR boosts motivation through the aspects of attention, relevance, and satisfaction [24]	Supporting the ARCS theory of motivation
14.	Zhang et al. (2020)	VR enhances students' attention, interaction, and interest [25]	Demonstrating the impact of VR on learning motivation

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No.	Author (Year)	Key Findings	Relevance to the Study
15.	Huang et al. (2021)	VR boosts engagement and motivation through repeated immersion [26]	Demonstrating sustained motivation
16.	Cheng & Tsai (2020)	Intrinsic motivation and immersion play a key role in VR learning [27]	Demonstrating the relationship between motivation and learning experiences
17.	Andreasen et al. (2019)	VR enhances enjoyment and the learning experience [28]	Enjoyment as an indicator of motivation
18.	Parong & Mayer (2020) dalam Liu (2022)	VR enhances emotions but can disrupt cognitive processes [2]	Demonstrating the dual effect of VR
19.	Cho & Park (2023)	VR enhances motivation in environmental education through interactive experiences [5]	Supporting Contextual Science Learning
20.	Tsirulnikov et al. (2023)	The VR lab boosts student motivation and engagement [29]	Relevant to experimental science learning
21.	Yang et al. (2024)	SVVR enhances motivation and deep learning [30]	Supporting the visualization of science concepts
22.	Abdelaziz et al. (2020)	VR boosts motivation and interest in learning operating systems [31]	Demonstrating the generalization of motivation
23.	Wang et al. (2024)	VR games enhance intrinsic motivation and understanding of astronomical concepts [32]	Supporting game-based science learning
24.	Zhong & Liu (2022)	VR boosts motivation through the novelty effect and engagement [33]	Explaining the mechanisms of VR motivation
25.	Ferrer et al. (2017)	VR enhances the embodied learning experience and motivation [34]	Supporting active learning

The synthesis of 25 selected articles (Table 2) reveals that most studies report a positive impact of Virtual Reality on students' learning motivation. VR enhances motivation through immersive experiences, interactivity, and increased engagement. These factors contribute to higher levels of interest, attention, and intrinsic motivation among students.

However, the findings also indicate that the impact of VR is not universally positive. Several studies show that excessive immersion or poorly designed VR environments can increase cognitive load, negatively affecting learning outcomes. This suggests that VR effectiveness depends not only on the technology itself but also on its pedagogical design and implementation.

Overall, the results across all sections indicate that VR has strong potential to enhance learning motivation in science education, particularly through immersive and interactive learning experiences. However, this potential is influenced by factors such as instructional design, technological accessibility, and the balance between engagement and cognitive load. These findings highlight the importance of integrating VR with appropriate pedagogical strategies to maximize its effectiveness.

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3.2. Discussion

3.2.1. Trends in Virtual Reality Publications in Science Education

The significant increase in publications over the past decade indicates that Virtual Reality has evolved from a mere technological innovation into an integral part of educational research, particularly in science education. This trend not only reflects technological advancements but also points to a growing need for more interactive, context-based learning approaches.

Previous research has shown that VR offers an immersive, authentic learning experience, thereby improving learning quality compared to conventional methods [3], [35]. In addition, the surge in publications after 2020 can be attributed to the acceleration of education digitization, which has driven the use of simulation-based technology in the learning process [4], [36].

Thus, this trend suggests that VR is not merely a fad, but has the potential to be part of a long-term transformation in science education.

3.2.2. Government Contributions to Publications

The dominance of countries such as the United States, China, and European nations indicates that the development of VR research is heavily influenced by the availability of technological infrastructure, access to VR devices, and research funding support. This finding aligns with studies showing that developed countries have a greater capacity to develop VR-based educational technology [35], [37].

However, the contributions of developing countries such as Indonesia, India, and Malaysia demonstrate the global expansion of VR research. This suggests that VR is increasingly being adopted as a learning tool, including in the context of science education, which requires the visualization of abstract concepts [5], [6].

As a result, the development of VR in education is no longer limited to developed countries and holds great potential for broader application, including in learning grounded in local knowledge, such as biotechnology.

3.2.3. Mapping of Academic Fields

The dominance of the field of Computer Science indicates that VR research remains firmly rooted in technological aspects, such as system development, software, and virtual environments. However, significant contributions from the field of Social Sciences point to a shift in focus toward the pedagogical and psychological aspects of learning [17], [38].

This development indicates that VR research is no longer focused solely on “how the technology is created,” but also on “how the technology is used in learning.” This aligns with the findings of Liu [2] and Shin [14], who emphasize that VR's effectiveness is determined not only by the technology itself but also by the learning experience it creates, including student motivation and engagement.

Therefore, this mapping of academic fields indicates the integration of technology and pedagogy, which is key to the development of effective VR-based learning.

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3.2.4. The Implementation of Virtual Reality in Science Education and Findings Related to Learning Motivation

A synthesis of 25 articles indicates that Virtual Reality has a significant impact on student learning motivation, particularly through increased engagement, interest in learning, and intrinsic motivation. Most studies suggest that immersive and interactive learning experiences are the primary factors driving increased learning motivation [16], [29], [39].

In science education, VR allows students to interact directly with phenomena that are difficult to observe in real life, such as molecular biological processes or abstract physics concepts. This has been shown to increase students' curiosity and interest in learning [12], [40], [41]. In addition, simulation- and game-based approaches in VR also help boost motivation by providing a more enjoyable and challenging learning experience [2], [24], [33].

However, research findings also indicate that the effects are not always positive. Some studies have shown that VR use can increase cognitive load, potentially disrupting the learning process if not properly designed [17], [42]. Furthermore, increased motivation is not always accompanied by a significant improvement in learning outcomes, suggesting that motivation and learning outcomes are interrelated but not always aligned [9].

The findings of this review can also be interpreted through motivational learning theories, particularly the ARCS Model and Self-Determination Theory (SDT). According to the ARCS Model proposed by Keller, effective instructional media should promote Attention, Relevance, Confidence, and Satisfaction to enhance students' motivation. The reviewed studies indicate that VR environments capture students' attention through immersive, interactive experiences, while contextual simulations increase the relevance of learning materials to real-world situations. Furthermore, game-based and exploration-oriented VR activities contribute to students' satisfaction and engagement during learning.

In addition, the findings are consistent with Self-Determination Theory, which emphasizes the importance of autonomy, competence, and relatedness in fostering intrinsic motivation. VR-based learning allows students to actively explore virtual environments and interact with learning content independently, thereby supporting learners' sense of autonomy. The interactive nature of VR also helps students develop competence through experiential learning and problem-solving activities. As a result, VR has the potential to enhance intrinsic motivation by creating meaningful and self-directed learning experiences.

These findings indicate that VR's effectiveness in enhancing learning motivation depends heavily on instructional design, particularly its integration with appropriate pedagogical strategies. In other words, VR is not merely a tool but must be designed as part of a learning ecosystem that supports meaningful learning experiences.

Overall, the results of this study indicate that Virtual Reality has strong potential to enhance students' motivation to learn in science education, particularly through immersive, interactive learning experiences. However, this effectiveness is not automatic; rather, it is influenced by instructional design, the complexity of the material, and student characteristics.

Furthermore, the limited number of studies that specifically focus on learning motivation as a primary variable indicates a research gap that warrants further investigation.

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Therefore, future research should develop VR-based learning models that focus not only on technological aspects but also on pedagogical strategies to optimize students' learning motivation, particularly in abstract science subjects.

Across the reviewed studies, a consistent pattern emerges showing that VR is most effective when immersive experiences are combined with appropriate pedagogical strategies. Studies involving interactive simulations, game-based learning, and contextual visualization tend to report higher levels of engagement and intrinsic motivation. However, studies also reveal that excessive immersion without instructional guidance may increase cognitive load and reduce learning effectiveness. Therefore, the findings across all sections suggest that the educational value of VR lies not merely in technological immersion but in its pedagogical integration to support meaningful and motivating learning experiences.

4. CONCLUSION

This study highlights that Virtual Reality (VR) has strong potential to enhance students' motivation to learn in science education through immersive, interactive, and contextual learning experiences. The findings suggest that VR effectiveness is influenced not only by technological features but also by its integration with appropriate pedagogical strategies to support meaningful learning experiences.

Theoretically, this study contributes to the literature by linking VR-based learning with motivational perspectives such as the ARCS Model and Self-Determination Theory. In practice, the findings have implications for educators in designing VR learning environments that balance engagement, instructional goals, and cognitive load.

However, this study is limited to Scopus-indexed journal articles published between 2016 and 2026 and focuses specifically on learning motivation in science education. Therefore, future research is recommended to explore the long-term impact of VR in diverse educational contexts and to develop more pedagogically integrated VR learning models. Overall, this study contributes to a broader understanding of how VR can support more engaging and student-centered science learning environments.

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