A Review on VR in STEM Education with Students and Teachers oriented Challenges

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Abstract

This research paper investigates the applications of Virtual Reality (VR) in education specifically targeting Science, Technology, Engineering, and Mathematics (STEM). This article explores how VR improves student learning outcomes, knowledge retention, engagement, and problem solving or critical thinking. We highlight the significant impact of VR in STEM Education for real life experiments, enhanced learning, visualization, and simulation-based learning. Despite promising benefits, challenges such as high costs, technological barriers, and content limitations persist. This research also categorize challenges related to students and Teachers from the literature and offers recommendations for further research to optimize its integration into diverse educational contexts.

Keywords

VR, Education, STEM, Students, Teachers, Higher Education

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1 Introduction

Education is a fundamental pillar of society, playing a crucial role in shaping individuals' knowledge, skills, and attitudes. Traditional educational approaches often rely solely on textbooks, lectures, and static visual aids, which can limit students' engagement and experiential learning opportunities [51]. We present the basic concepts related to Extended, Augmented and Mixed Reality (XR, AR and MR, respectively) and then reviews the applications of VR in education especially targeting STEM, categorizing them into specific domains (Subject-Wise) to provide a comprehensive understanding and to view teachers' and students' related challenges.

VR was originally developed for video gaming and entertainment [31]. VR is a cutting-edge technology that uses computer-generated simulations to create immersive, 3D environments that interact with digital content in a way that feels incredibly realistic [15]. VR connects virtual things with real-world elements to generate interactive educational environments [36]. With everything from virtual field trips to historical landmarks to substantively realistic simulations of laboratory experiments, VR drives active learning, promotes student engagement, and enhances knowledge retention across disciplines. However, despite its immense potential, integrating VR into educational systems has some challenges including high costs, limited access, and the need for teacher training to maximize its effectiveness.

Recently, VR has captured a lot of attention in the education sector because of its ability to boost student engagement and support hands-on learning [14]. By placing learners in interactive environments, VR can recreate real-world situations that are often tough to mimic in a traditional classroom which enhances the overall educational experience [23]. The prominent advantage of the VR in education is enhancement of student engagement and motivation for a deeper understanding into STEM subjects. As technology advances and becomes more affordable, VR is likely to play an increasingly important role in shaping future educational practices, making learning more engaging and tailored to individual needs. The exciting world of VR is an aid in changing conventional educational and learning methodology into a game-changing tool. These perspectives indicate how VR can transform learning experiences by making difficult concepts more understandable and engaging for students [32].

In this research we discuss the following key points:

- The study categorizes and analyzes VR applications in *education* across various domains under *STEM* education subjects like Science, Technology, Engineering, and Mathematics that provides an extensive overview of existing literature.
- This review identifies how VR significantly increases student engagement, learning outcomes and retention through immersive, interactive learning experiences that make complex concepts more accessible.
- The research highlights challenges faced by *students and Teachers* and their opportunities to adopt VR effectively.
- The study identifies *key barriers* such as high costs, technological limitations, motion sikness and accessibility issues, while offering solutions and recommendations to overcome these challenges by maximizing VR's educational potential.

2 Literature Review

This section explores the impact of VR on student learning outcomes, knowledge retention, and students engagement supported by insights from relevant research papers.

In the realm of STEM education, the use of VR enables students to dive into complex scientific ideas and perform virtual experiments that might be too risky or impractical in real life [30] e.g,. VR applications can mimic chemical reactions or illustrate physical phenomena, helping students grasp abstract concepts more effectively. Additionally, VR-based STEM education has been shown to boost motivation and interest among students by making learning more engaging and accessible [40]. VR improves students attention for learning in the following aspects.

2.1 Enhanced Learning Outcomes

VR significantly enhance learning outcomes in STEM education. Authors from [26] indicate that VR provides students with the ability to interact with complex concepts in a three-dimensional (3D) environment, leading to deeper understanding and better retention of information. For instance, research has demonstrated that students using VR to study human anatomy achieved higher post-test scores compared to those using traditional methods, highlighting the effectiveness of VR in complex subjects [8]. VR improves students learning outcomes by 3D conceptual design and presentation experience [25].

2.2 Improved Knowledge Retention

Knowledge retention is a critical aspect of STEM education, and VR has been found to be highly effective in this regard. This is particularly evident in subjects like engineering and biotechnology, where VR simulations have been shown to enhance students' ability to retain information and apply it in real-world scenarios [34]. VR enhances the learning experience and knowledge retention of students by providing a beneficial learning aid. To ensure, future utilization of such systems, students' perceptions were examined regarding utilizing VR as an educational tool in the Faculty of Information [4].

2.3 Increased Student Engagement

Student engagement is a key factor in determining the success of any educational intervention, and VR has been found to significantly increase engagement levels in STEM education. VR enhances group work skills and self-regulated learning [1] and self-efficacy and experience [14] among students.

VR motivates students to participate actively in the learning process, leading to higher levels of involvement and interest in the subject matter [20]. Moreover, VR offers personalized learning experiences, allowing students to explore concepts at their own pace and in a manner that suits their individual learning styles. This personalized approach has been shown to increase students' motivation and interest in STEM subjects, particularly among at-risk students who may benefit from the interactive and engaging nature of VR [16].

2.4 Impact on Problem-Solving and Critical Thinking

VR has also been found to enhance students' problem-solving abilities and critical thinking skills [4]. This is particularly evident in studies where students using VR simulations demonstrated improved problem-solving skills and a deeper understanding of scientific principles [39]. Furthermore, VR provides students with the opportunity to experiment and explore different solutions to problems in a risk-free environment, fostering a sense of creativity and innovation. This aspect of VR is particularly beneficial for STEM education, where the ability to think critically and problems solving approaches is highly valued [11].

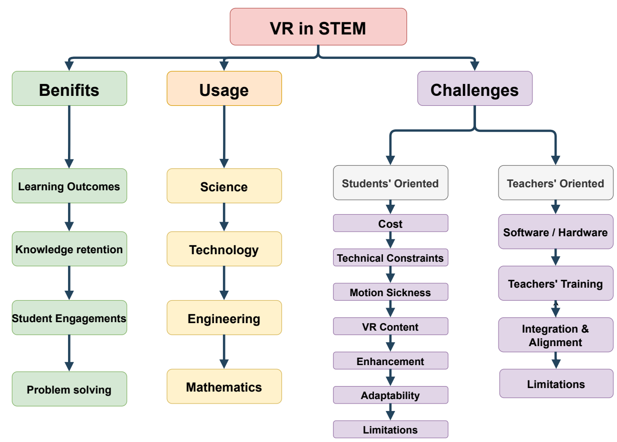

Figure 1: Constructive hierarchy of this paper

3 Methodology

To ensure relevancy in the literature, we applied the following inclusion and exclusion criteria in selecting studies.

Inclusion Criteria

- Peer-reviewed journal articles, conference papers, or systematic reviews.
- Papers that focus VR, AR, MR, or XR in STEM education.
- Studies involving primary education, K–12, higher education.
- Articles written in English Language.
- Content directly relevant to learning outcomes, usability, pedagogical impact, or implementation challenges in educational settings.

Exclusion Criteria

- Studies not related to education.
- Articles focusing solely on non-STEM disciplines unless explicitly interdisciplinary with STEM.
- Redundant publications or replications without significant new insights.
- Articles written in other than English Language
- Outdated studies focusing solely on obsolete technologies or platforms.

4 VR in STEM Domains

VR has emerged as a transformative technology in education, offering immersive and interactive learning experiences across diverse fields [12]. This review synthesizes existing research on the challenges, benefits, and impact of VR in STEM education and the hierarchy of the paper is depicted in Fig. 1.

4.1 VR in Science

In biology systems, the function such as macromolecules (proteins, RNA, and DNA) and their complexes 3D structural models, molecular graphics have been using VR for better students learning [47]. VR in physics received much more attention in terms of student perception, particularly in self-efficacy and experience, followed by satisfaction, motivation, and engagement. Authors from [41] identifies that there is significant implications for future research, particularly as a teaching tool in chemistry. With a basic smartphone and software, users may now access complicated chemical experiences through the VR, bypassing the financial, geographic, and physical limitations of actual labs and their pricey equipment[22].

4.2 VR in Technology

VR technology is now becoming cost-effective for application in many domains including Technology and is expected to become even more in the future. VR has been used in various technologies including green building landscape design environmental industry 4.0 transportation aerospace . Authors from [9] presented how technology was used to support students to become content creators in an integrated STEM learning environment. VR provides a functional approach to analyzing STEM applications in complex concepts in various technologies [29]. The laboratory environments of technologies assist students in learning with application tools based on web-based e-learning environments and mobile learning platforms[21].

4.3 VR in Engineering

The VR technology have been integrated in the engineering field. ViRILE VR-based software designed for undergraduate chemical engineers that stimulate the configuration and operation of plant Polymerization[42]. VR is used in the field of mining and civil engineering to enhance occupational health and safety practices[44]. Authors from [48] use VR in civil engineering education by emphasizing multi-perception teaching, where multiple senses (vision, hearing, and touch) enhance learning efficiency. Electrical engineering students had a highly positive attitude toward the use of the integrated AR with e-worksheet in the electrical machines course. By using this, it had a positive and significant direct effect on engineering students' attitudes.[50].

4.4 VR in Mathematics

Research from [9] made a design of the robots helped students learn and practice mathematical concepts in an integrated way, presenting students with challenges of increasing difficulty. The use of robotics helped students "connect the skills learned in mathematics. In the filed of mathematics the game based learning is mainly used for abstract concepts rather than complex ones [43]. VR math and GeoGebra provide 3D drawing space that enhances spatial understanding among students[45]. VR and gamification can further enhance mathematical performance by making learning more engaging and fun[7].

5 Students' vs Teachers Oriented Challenges

While VR offers numerous benefits for STEM education, there are also challenges and considerations that need to be addressed. Some of the challenges drawn from the literature for Teachers and Students are mentioned below and subject-wise can be seen in Table 1. The challenges faced by students and teachers using VR are as follows:

5.1 Students' oriented challenges

- **Cost**: Implementing VR hardware is expensive, making it unaffordable for many institutions and individuals. Significant investment is required to transform traditional laboratories into VR labs [5].
- **Technical Constraints**: The need for high-quality VR equipment and the potential for cybersickness, can hinder the effective implementation of VR in educational settings [24]. There are various VR devices available, and finding the right one for each tailored learning environment remains a challenge. Studies from [37] show that popular devices such as Samsung Gear enhances student learning experiences.
- **Motion Sickness:** Many students experience motion sickness when using VR for extended periods because their bodies struggle to adjust to the disconnect between what they see in the virtual environment and what they physically feel. This sensory mismatch can lead to dizziness, nausea, and discomfort, making it difficult for students to focus on learning which is due to visual fatigue [5],[13].
- **VR Content:** The development of VR content requires careful consideration of pedagogical design to ensure that it aligns with learning objectives and is accessible to all students [46]. It is also mentioned that VR-based interactive learning should be carefully designed for different tasks using guided instructional approaches, extending beyond traditional classrooms to settings like field trips and museums [37].
- **Enhancement:** There is also a need to improve the usability and effectiveness of laboratory environments for students. Authors addressed this by enhancing interaction with the lab objects and facilitating remote collaboration [6].
- **Adaptability:** Some students are not used to VR technology, they may find it difficult to move around in the virtual world and not fully take part in lessons [28].
- **Limitation:**Researchers found that collaborative learning with six or seven students is easier for instructors to manage due to equipment quantitative limitations [18].

5.2 Teachers' oriented challenges

Teacher training is another critical factor in the successful integration of VR in STEM education. Educators need to be equipped with the necessary skills to effectively utilize VR tools and design immersive learning experiences that enhance student outcomes. Followings are some key insights from the literature.

Table 1: Challenges of VR in STEM Education

STEM Subject	Opportunities	Student Challenges	Teacher Challenges
Science	Virtual labs reduce costs, enable experiments, and enhance understanding and learning outcomes [37, 49].	Lack of tactile experience, motion sickness, hardware dependency [2, 49].	High simulation costs, limited research on VR learning impact [13, 33].
Technology	Immersive coding, AI model visualization, self-directed learning [2, 28].	Limited VR programming tools, complex debugging, high-performance computing needs [6].	Lack of VR curricula, integration challenges, frequent software updates [33].
Engineering	Simulates design analysis, enhances visualization, supports virtual prototyping [10, 13].	Limited physical interaction, incomplete physics simulation, group project difficulties [2].	High software costs, lack of collaboration tools for remote teamwork [28].
Mathematics	Visualizes abstract concepts, supports gamified learning [2, 27].	Preference for traditional methods, limited VR tools for advanced topics [27].	Difficulty designing VR applications, lack of teacher training [33].

- **Teacher's Training:** Without adequate training and support, the potential of VR to transform STEM education may not be fully realized [2]. A survey indicated that they would be willing to adopt VR if they received sufficient training [17].
- **Software/ Hardware:** Teachers that are not familiar or comfortable with technology may find it more difficult to visualize how to use it for teaching [38]. Teachers must be familiar with software and Hardware to fully convert the traditoinal classroom into VR-enabled classrooms [5].
- **Integration and Alignment:** The teachers need to develop new instructional strategies that effectively integrate VR into the curriculum [3]. They also face difficulties finding VR content that aligns with their curriculum, as there is still a shortage of high-quality, subject-specific VR learning materials [37]. Authors highlighted the challenge of finding or creating VR experiences that align with learning objectives across subjects [35].
- **Limitations:** The lack of high-quality, curriculum-aligned VR content can limit the topics and activities available, reducing its effectiveness as a learning tool [19].

These challenges highlight the need for careful planning and support to effectively implement VR in educational settings.

6 Conclusion

This survey highlights the significant benefits of VR in education across various subjects in STEM and highlights its challenges related to students and Teachers. The incorporation of VR in STEM education has been shown to have a positive impact on students by providing immersive, interactive, and personalized learning experiences. VR enhances students' understanding of complex concepts, improves knowledge retention, and increases engagement and motivation. Additionally, VR simulations prepare students for real-world problem-solving and critical thinking, essential skills. However, successful integration of VR in education requires addressing technical challenges, ensuring accessibility, and providing adequate teacher training and familiarity with software and hardware. VR technology continues to evolve, its potential to transform STEM education is immense, offering new opportunities for students to engage with complex concepts in innovative and effective ways. The proper use of software/hardware and instructional strategies may open various directions in the future research with in VR based educational settings.

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