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Integration of Virtual Reality in STEM to Enhance Problem Solving Skills in Science Learning in the 21st Century: A Review

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Abstract: One of the most exciting innovations today is Virtual Reality. VR simulations expand the variety of real-world applications for students to explore, Virtual reality with STEM Approach is important to encourage students to actively seek or explore information and solve learning problems creatively, while thinking critically about the phenomena they encounter. For this reason, this study aims to examine the Integration of Virtual Reality in STEM to improve problem-solving skills in science learning in the 21st century: A Review. This review was conducted based on the review method. The results of this study explain about Benefits of VR in Education: Immersive Learning, Safe Practice Simulations, Enhanced Conceptual Understanding, Enhanced Creativity, Access to Global Experiences, Adaptation to Different Learning Styles, Collaborative Learning, Increased Learning Retention, More Effective Distance Learning ; 4 aspects in STEM : Science, Technology, Engineering, Mathematics formulate problems, solve problems and interpret solutions to mathematical problems in applying various different situations; The Role of Virtual Reality in Enhancing Problem-Solving Abilities in Science Education for the 21st Century : Visualizing Complex Ideas and Data, Collaborative Learning and Global Connections, Immersive Experiences and Real-World Simulations, Equitable Access and Inclusivity in STEM Education, Challenges and Considerations for Implementing VR in STEM Learning.

Keywords: Problem solving skills; STEM; Virtual reality

Introduction

As education continues to change, educators and decision-makers need to understand emerging technologies that are transforming the learning process and engaging students (Haleem et al., 2022; Li et al., 2022). One of the most exciting innovations today is Virtual Reality. Virtual reality (VR) has revolutionized education by offering immersive experiences that stimulate students' curiosity, enhance their understanding, and empower them to become active learners (Javaid et al., 2024; AlGerafi et al., 2023). VR is transforming STEM education by providing immersive experiences that take students into new dimensions—both real and imagined. Students can explore distant planets, dive into the depths of the ocean, or even experience historical moments from the past thanks to VR technology. These immersive learning opportunities create a level of interest and excitement that is hard to match with traditional teaching methods. Virtual reality simulations allow students to learn through hands-on experience and apply principles to the real world. For example, students can perform surgery in a virtual operating room, conduct experiments in a virtual chemistry lab, or design and test engineering prototypes in a virtual context.

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One of the advantages of VR simulations is that they create a safe and structured environment for students to experiment (Żammit, 2023; De Lorenzis et al., 2024). They can repeat simulations until they achieve mastery while making mistakes, learning from them, and correcting them. This hands-on approach develops analytical and critical thinking skills as well as a deeper understanding of fundamental concepts. Furthermore, VR simulations expand the variety of real-world applications for students to explore. For example, students can model real-world situations in fields such as environmental science, aeronautical engineering, or architectural design. In this way, students hone essential skills and gain valuable experience to prepare them for careers in STEM fields (Galvez et al., 2024; Black et al., 2021). To hone students' critical thinking skills, science, technology, engineering, and mathematics (STEM) curriculum can be implemented innovatively in the era of industrial revolution 4.0 and educational freedom.

Critical thinking is a structured and proactive cognitive process that helps individuals assess their views of others (Leighton et al., 2021; Dwivedi et al., 2021). The acronym STEM represents an interdisciplinary approach that brings together mathematics, science, technology, and engineering (Stevenson et al., 2024). The strategy based on these four elements provides an ideal balance between learning that focuses on solving challenges in personal and professional life and real-world issues. This method is able to provide an integrated learning system and active learning because it requires all four components simultaneously to solve problems. The responses given reflect the extent to which students can relate abstract concepts from various perspectives (Southworth, 2022; Chan & Lee, 2021). This STEM approach is oriented towards knowledge, technology, engineering, and mathematics as the four pillars of science. According to research, the application of STEM can also increase children's creativity, help them explore information, and provide solutions to problems based on their investigations. The STEM method gives students the opportunity to face challenges and find solutions. This continuously develops their potential.

STEM is very relevant for fields that require precision and deep understanding, such as biology education. Students who study biology need to be actively involved, becoming creative thinkers who are able to critically analyze events around them (Weng et al., 2022; Kwangmuang et al., 2021). Students' scientific attitudes and critical thinking skills can be influenced by the STEM approach applied in the classroom. To achieve these learning objectives, teachers as the director of the learning process must carefully evaluate the models and techniques applied in the classroom. The application of the STEM approach is very important because it encourages students to be active in seeking or exploring information and creatively overcome learning challenges while thinking critically about the phenomena they face.

Although research on Virtual reality Integration has been widely conducted such as The future of prejudice reduction research: A critical review of the role of virtual reality (VR) (Chen & White, 2024), Publication performance and trends in virtual reality research in education fields: a bibliometric analysis, (Elaish et al., 2024), there has been no research that specifically examines Virtual reality Integration in STEM to improve problem-solving skills in science learning in the 21st century: a systematic review. Therefore, this study aims to explore the integration of virtual reality in STEM to improve problem-solving skills in science learning in the 21st century: A review.

Method

This study uses a review method. The framework is designed to classify data sources and general information studied in the study. The author attempts to collect information from previous studies related to the variables. The full article is published in the 2015-2023 international journal, indexed in the database, and themed the Integration of Virtual Reality in STEM to Enhance Problem Solving Skills in Science Learning in the 21st Century: A Review.

Result and Discussion

Benefits of VR in Education

Some of the benefits of virtual reality are (Lee et al., 2020; Oke et al., 2023; Barreda-Ángeles & Hartmann, 2022) : Immersive Learning: VR allows students to fully engage in a virtual learning environment. They can "be" in hard-to-reach places like outer space or under the sea, making the subject matter more vivid and understandable; Safe Practice Simulations: In fields like medicine or engineering, VR allows students to practice in realistic situations without the risk of real-world harm. For example, aspiring doctors can perform virtual surgical procedures without the fear of making a fatal error; Enhanced Conceptual Understanding: VR helps students understand complex concepts with three-dimensional visualizations. This is especially useful in science and math classes, where visualizations can facilitate understanding; Interactive Learning: VR makes learning interactive, allowing students to interact with virtual objects or scenarios, which increases engagement and motivation to learn; Access to Global Experiences:

VR allows students to visit historical sites, museums, or global landmarks without leaving the classroom.

This broadens their horizons about the world and different cultures; Enhanced Creativity: VR gives students the space to be creative and innovative in a virtual environment. They can design and build objects, create scenarios, or create works of art in the VR world; Collaborative Learning: Through VR, students can work together in a virtual environment despite being in different locations. This supports collaboration on projects that require teamwork; Adaptation to Different Learning Styles: VR allows for the adaptation of learning methods to different learning styles. Visual, kinesthetic, and auditory learners can all benefit from an approach that fits their needs; Increased Learning Retention: Immersive learning experiences through VR have been shown to increase information retention. Students are more likely to remember what they learn in an interactive and engaging environment; More Effective Distance Learning: In the context of distance learning, VR allows students to feel more connected to the subject matter and their classmates, reducing feelings of isolation and increasing engagement.

4 aspects in STEM

Science is the ability of knowledge in understanding natural phenomena in real life, related to physics, chemistry, biology; Technology is the ability of students to recognize, develop, analyze new technologies that can support the learning process; Engineering is the ability to develop technology through engineering design processes in the form of learning projects; Mathematics is the ability to analyze, formulate problems, solve problems and interpret solutions to mathematical problems in applying various different situations (Aydin Gunbatar et al., 2024; Ángel-Uribe et al., 2024; Jones et al., 2024).

The Role of Virtual Reality in Enhancing Problem-Solving Abilities in Science Education for the 21st Century

Visualizing Complex Ideas and Data

Virtual reality has emerged as an effective tool for representing and understanding complex scientific concepts in STEM education (Acevedo et al., 2024). VR immerses students in complex phenomena that are usually difficult to visualize in a traditional classroom setting. With the help of VR, scientific concepts come to life, making difficult topics easier for students to understand. For example, students can experience a virtual journey inside the human body to learn how the complex circulatory system works or observe chemical processes at the molecular level. By actually experiencing these phenomena, students gain a deeper understanding and stronger retention of STEM fundamentals. Additionally, VR gives students the opportunity to interact with and process large datasets in STEM subjects. Through immersive data visualization, students can explore and analyze complex information, such as astronomical data, genetic sequences, or climate-related data. This interactive method of data exploration encourages analytical and critical thinking, allowing students to gain valuable insights. One of the well-known platforms that demonstrates the effectiveness of VR in data visualization is Tuva (Lønne et al., 2023). Students with access to these immersive virtual environments can investigate real-world data (Silseth et al., 2024). They can discover patterns, draw conclusions, and develop data literacy skills essential to success in the digital age by interacting with graphs, charts, and simulations in a virtual setting. Interactive and Engaging Learning Environments.

One of the key benefits of VR is its ability to offer realistic simulations and scenarios that allow students to apply their knowledge in practical contexts (Lowell & Tagare, 2023; Asad et al., 2021). VR allows students to engage in real-world STEM interactions, whether exploring the surface of Mars or creating and testing a technology prototype (Tene et al., 2024; Guerra-Tamez, 2023; Zhang et al., 2024). These dynamic, detailed settings enhance students' problem-solving skills and encourage collaboration among students, while also sparking their curiosity. PhET is an example of a VR platform that exemplifies an interactive and engaging learning setting. PhET provides a wealth of virtual simulations across a range of STEM disciplines that allow students to investigate scientific phenomena, conduct experiments, and master concepts in greater depth. Students actively engage with the curriculum through interactive features and lifelike simulations, enhancing their learning experience and retention.

Collaborative Learning and Global Connections

VR's potential to support collaboration is a major benefit. Students from all over the world can come together in a virtual platform to solve complex STEM challenges (Wang et al., 2021). With virtual reality technology, students can come together to tackle challenges, share ideas, and gain insights from multiple perspectives. For example, in an integrated virtual environment, students can work together to design virtual models, conduct experiments, or develop technical solutions. In addition to enhancing collaboration and communication skills, this collaborative approach exposes students to different cultural backgrounds and ways of thinking. VR also provides opportunities for students to interact with experts, scientists, and professionals from a variety of fields (Sukmawati et al., 2022; Chernikova et al., 2020). They can visit scientific research facilities, explore famous sites, and communicate with practitioners from around the world through virtual field trips and guest lectures. This international connection broadens students' horizons, introduces them to a variety of STEM careers, and motivates them to take their passions global.

Immersive Experiences and Real-World Simulations

One way VR is revolutionizing STEM education is by providing students with immersive experiences that transport them to new realms—both real and imagined. Students can travel to distant planets, dive to the bottom of the ocean, or even step back in time to witness historical events, thanks to VR. These immersive learning opportunities offer a level of excitement and engagement that is unmatched by traditional teaching methods. Virtual reality-based simulations allow students to learn through hands-on experience and apply principles to the real world (Merchant et al., 2014; Abbas Shah et al., 2024). For example, students can perform medical procedures in a virtual operating room, conduct research in a virtual chemistry lab, or design and test engineering prototypes in a virtual context. These simulations give students the opportunity to practice critical thinking and problem-solving skills. One of the benefits of VR simulations is that they create a safe, structured environment for experimentation (Luo et al., 2021; Holuša et al., 2023). Students can repeat the learning process until they master it, while making mistakes, learning from them, and improving their results. This hands-on approach enhances problem-solving and critical thinking skills and leads to a deeper understanding of core concepts. Additionally, VR simulations expand the variety of real-world applications that students can investigate. For example, students can model real-world situations in fields such as environmental science, aerospace engineering, or architectural design. In this way, students develop important skills and gain valuable experience that will prepare them for future careers in STEM (Stehle & Peters-Burton, 2019; Drymiotou et al., 2021).

Equitable Access and Inclusivity in STEM Education

VR's ability to address resource inequities is a key benefit. Students can practice in virtual labs to run simulations that mirror real-world investigations in schools that do not have laboratory facilities or equipment. This allows them to engage in learning experiences that would otherwise be unavailable due to financial or technical constraints. Additionally, by accommodating a diverse range of learners, including those with disabilities, VR promotes diversity in STEM education. VR's immersive and interactive features support a variety of learning styles and interactions. Visuals, sounds, and interactive elements enhance each student's understanding and engagement (Oje et al., 2023; Cinar et al., 2024). Additionally, VR can offer adaptive features and assistive technologies such as text-to-speech, vibration feedback, and closed captioning that make STEM teaching more accessible to students with disabilities (Chalkiadakis et al., 2024). By leveraging VR, educational institutions can build inclusive learning environments where every student can actively participate and succeed in STEM subjects. In this digital age, all learners have the opportunity to succeed when schools make the most of VR to increase accessibility and inclusivity in STEM teaching. VR opens up more access, gives everyone the opportunity to gain information, and provides diverse learners with the tools they need to explore and excel in STEM subjects.

Challenges and Considerations for Implementing VR in STEM Learning

The use of VR in STEM education presents a number of challenges and concerns (Jiang et al., 2025; Refmidawati, 2023). In order to successfully integrate VR into their educational programs, one must be aware of these issues. The cost involved is one of the main challenges when considering the use of VR . The initial investment in VR technology, including the cost of the headgear, software, and content, can be quite high. However, it is important to view this investment as a long-term commitment to STEM education. Schools can mitigate the cost burden by exploring and researching more cost-effective options, partnering with VR manufacturers, or considering rental schemes (Habib et al., 2022; Ariya et al., 2024). Technical issues are another area to consider. Schools need to ensure that their technology, network capacity, and other infrastructure can support VR applications. Working with the IT department or seeking assistance from VR experts can help overcome technical issues and ensure a smooth installation process. It is also important to provide the necessary training and support for teachers if VR is to be successfully integrated into STEM education. Teachers must be equipped to effectively implement VR in their classrooms with the necessary skills and knowledge (Ironsi, 2023; Adelana et al., 2023).

With the support of professional development programs, workshops, and ongoing support, teachers can be equipped to navigate VR technology and make the most of it. Challenges can also be minimized through collaboration and exchange of best practices among educators and institutions. Schools can share resources, collaborate on VR initiatives, and learn from each other's experiences through the formation of communities of practice. This collective effort fosters innovation and raises the overall standard of VR integration in STEM classrooms. Finally, it is critical to align curriculum goals and outcomes with VR use (Villena-Taranilla et al., 2022). VR should be used to enrich and deepen students' understanding, not just as a novelty. Schools can ensure that VR experiences are an integral part of their STEM education programs by integrating them into existing lessons and matching them to specific learning objectives.

Conclusion

Students from all over the world can come together in virtual platforms to tackle complex STEM challenges. With virtual reality technology, students can come together to face obstacles, share ideas, and gain insights from multiple perspectives. VR can offer adaptive features and assistive technologies such as text-to-speech, vibration feedback, and closed captioning that make STEM teaching more accessible to students with special needs. By leveraging VR, educational institutions can build inclusive learning environments where every student can actively participate and succeed in STEM. In this digital age, all learners have the opportunity to succeed when schools make the most of VR to increase accessibility and inclusivity in STEM teaching.

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Conceptualization, methodology, validation; formal analysis, investigation; resources, data curation, A. A.A. A; R. R. P. M. S., writing—original draft preparation, writing—review and editing, visualization, S. A. A., R. A. H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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