

# A Review on Introduction of Immersive Technology in STEM Education

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**Abstract:** *With an emphasis on academic performance and engagement, this review attempts to evaluate the effect of implementing immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR), on students in Science, Technology, Engineering, and Mathematics (STEM) education. Following the PRISMA guidelines, peer-reviewed studies published between 2002 and 2024 were thoroughly searched. The PICOS framework guided the selection of studies assessed for methodological quality. Descriptive analysis was used to determine the link between the type of technology and educational outcomes. Through the use of these technologies, learning experiences may be made more immersive and participatory, bridging the gap between theory and practice. Immersion technologies are full of promise, but their successful application will depend on addressing issues including initial costs, teacher preparation, and technical concerns. Future studies should concentrate on removing these obstacles and looking into creative approaches to include immersive technologies in STEM curricula. The review underscores the potential of immersive technology to revolutionize STEM education by offering stimulating and productive learning opportunities that enhance student performance.*

**Keywords:** STEM Education, Virtual Reality (VR), Augmented Reality (AR), Learning Outcomes

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## 1. Introduction

Science, technology, engineering, and math are all included in the multidisciplinary field of STEM education. By collectively offering a strong foundation for people to flourish in a world that is changing quickly, it plays a critical role in determining students' future performance in the workforce (Mehdi Roopaei 2021, Jiayan Zhao 2020, Thomas K.F. Chiu 2023). Because one-third of all occupations in industrialized countries are thought to be tied to STEM subjects, experts stress the need for STEM education (Yeping Li 2020). By offering immersive learning opportunities which traditional techniques cannot, this innovative methodology seeks to transform STEM education. To improve student engagement and learning outcomes, immersive technologies like augmented reality (AR) and virtual reality (VR) as well as their integrations, are being used in educational settings more and more (Talia Tene 2024, Mehdi

Roopaei 2021, Nikolaos Pellas 2020, Jiayan Zhao 2020). As a result, many educational institutions have embraced cutting-edge technology to improve learning, particularly in STEM fields. Numerous efforts (Jane Crayton 2015, Ishan Maheshwari 2020, Nikolaos Pellas 2020, Nur Zahira Mohamed Zahir 2023) have already been started. The rapid advancement of new technology has had an impact on numerous aspects of society, including the potential methods of instruction and learning.

Nevertheless, these new environments and knowledge are difficult for teachers to access in a way that is both relevant and instructive (Mehdi Roopaei 2021). There aren't enough suitable frameworks and design methods for technologies and computer-supported collaborative learning in STEM, according to a study by Nur Zahira Mohamed Zahir (2023). The study showed that there is an immediate need to investigate design strategies to develop simple but efficient STEM teaching strategies. In Malaysia, there are few attempts to establish a powerful STEM education system. Unfortunately, issues like declining student interest and engagement in STEM fields, a shortage of qualified teachers, inadequate funding, and social and cultural barriers make it a tough time to implement. In order to enhance students' curiosity and interaction in STEM education, this review will investigate how to leverage immersive technologies completely.

## **2. Problem Statement**

One of the many issues facing STEM education is the lack of a thorough examination of the effect of immersive technology on student outcomes. Research frequently separates technology and education, ignoring problems particular to STEM fields such as falling student interest (Hsu & Fang, 2019). Furthermore, comprehensive STEM approaches in K–12 education are hindered by the lack of qualified teachers and insufficient professional development. Multiple viewpoints on how STEM should be implemented in classrooms further reinforce inefficient methods, which lower student engagement and motivation. Aside from that, the gender gap is also a significant problem in STEM education, especially in the highest-paying careers like engineering and computer science. When people underestimate their math and science abilities, their interest in STEM education decreases. Studies reveal that only a few women continue to pursue STEM careers, which limits the financial opportunities available to women employed in STEM-related fields. To counteract social effects that deter girls from pursuing STEM occupations, initiatives that can increase their confidence in these disciplines must be made from an early age.

Furthermore, it is crucial to overcome the difficulty of creating integrated STEM lessons that support students' creative, cooperative problem-solving while maintaining or improving test scores (Lee et al., 2018). Since many lesson plans still trend toward didactic methods, teachers frequently struggle to implement pedagogical tactics that truly engage students in STEM learning. STEM curriculum design also needs to take into account the interests and skills of the students, which means developing technologically aided modular engineering problems. Students' involvement and overall feedback are further reduced when they are unable to recognize the relation of STEM to real-world problems due to a lack of appropriate pedagogical tools and a supportive school environment (Lee et al., 2018). All things considered, because of these interrelated difficulties, student evaluation of STEM education has been disappointing. Consequently, the purpose of this research is to investigate how immersive technologies might help overcome the obstacles that STEM education faces and improve learning outcomes, motivation, and student involvement. This review attempts to aid in the creation of creative

and successful methods for teaching and learning in STEM subjects by analyzing the research on immersive technologies in these domains.

### 3. Methodology

The integration of immersive technologies, particularly augmented reality (AR) and virtual reality (VR), in STEM education is the main emphasis of this systematic study. Comparing immersive technologies (AR, VR, MR) to traditional teaching approaches, the goal is to determine which one improves student engagement and academic achievement more. To do this, the PICOS framework was utilized to develop the study question "In comparison to traditional teaching methods, what are the effects of immersive technologies (AR, VR, MR) on student learning experiences and engagement in STEM education?"

Page et al. (2021) provide the PICOS framework, as Table 1, which aids in defining specific research questions and choosing appropriate research for systematic reviews. To guarantee thorough reporting of the study process, this review adhered to PRISMA guidelines, as shown in Figure 1 (Page et al., 2021). The review spans the years 2002-2024 to document the development and integration of immersive technologies in STEM education and enable examination of their effects on the teaching and learning of fundamental STEM subjects.

**Table 1: Components of the research question according to the PICOS framework.**

<b>P</b>	<b>Population</b>	<b>Students enrolled in STEM education programs</b>
I	Intervention	Immersive technologies (AR and VR)
C	Comparison	Traditional teaching methods
O	Outcome	Student learning experiences, engagement, and outcomes
S	Study Design	Studies that use both qualitative and quantitative methods to investigate the use of immersive technologies in STEM education.

#### 3.1 Identification

The identification procedure must be carried out first before delving into deeper PRISMA guidelines. For this review, multiple databases were searched thoroughly any related studies by using Google Scholar. The primary databases included ResearchGate, IEEE, PubMed, ScienceDirect, SpringerLink, and MDPI, as these databases are very well known for providing comprehensive data and information on scholarly research. While for the search process, a combination of keywords was used, such as "augmented reality", "mixed reality", "immersive technologies", "STEM education", "student engagement", "learning outcomes", "student performance", "teaching" and "learning". Boolean operators that consist of AND, OR, NOT and truncation were employed to refine the search results. In this review, search strategies such as combining different keywords, using Boolean operators, and applying truncation were employed to ensure all relevant studies were reviewed. Additionally, filters such as language and document type were purposely utilized to restrict the results. After the search process, the results were screened based on titles and abstracts to in-depth identify potentially relevant articles. Manual comparisons were used to eliminate duplicate articles. This procedure is important to produce relevant articles that are able to serve as the foundation for further analysis.

#### 3.2 Screening

There were 96 relevant articles found after a thorough database search. After a variety of databases were searched, the titles and abstracts were sorted and examined. At this preliminary stage, only peer-reviewed journal articles were taken into consideration for additional

assessment. Once duplicate items were removed, there were 95 articles remained. Following inclusion criteria in compliance with the PRISMA guidelines and the research objectives, these papers underwent a thorough screening procedure for titles and abstracts. The following are examples of the inclusion criteria:

- STEM education is a distinct topic covered in articles produced at different educational levels (K–12, college, or professional training).
- Studies on the application of simulators in STEM integration and the evaluation of learning objectives concerning the use of immersive technologies, such as augmented reality (AR), virtual reality (VR), and immersive virtual environments (IVEs), are required.

Articles that did not meet these criteria were excluded from further review, resulting in 56 articles advancing to a comprehensive full-text review to assess their suitability for inclusion in the systematic review. During the second phase, studies were assessed according to how they measured students' academic achievement and use of immersive technologies in STEM education. It was necessary to assess academic achievement using techniques like grades, subject-specific measures, and pre-and post-test results. In the same way, objective measurements like time spent on assignments, surveys, observable behaviors, or physiological readings (heart rate, eye tracking, etc.) were necessary to measure student interest. Excluded studies lacked explicit evaluations of academic or involvement standards. Consequently, this led to the removal of 14 out of the 56 publications, leaving 42 studies that provided insightful information about how immersive technologies affect STEM learning outcomes and engagement.

### **3.3 Eligibility**

The following criteria were used to evaluate research as part of the eligibility process:

- Emphasize immersive technologies in STEM fields that use AR and VR.
- The effects of immersive technologies in contrast to standard teaching methods are compared.
- Student Learning Outcomes that evaluate student involvement, experiences, and results.
- Utilizing both qualitative and quantitative methodologies.

56 of the 95 publications that were first found were chosen for full-text review. Ultimately, 16 of the 42 papers were excluded due to inconsistencies with the eligibility criteria. The remaining 26 papers were included in the systematic review for in-depth analysis. However, these excluded papers can be used for valuable information to craft the discussions in Section 7.1. This procedure guaranteed that the systematic review included only pertinent, excellent studies.

## **4. Results**

This systematic research evaluated the impact of immersive technology on improving academic performance and student engagement in STEM education, adhering to PRISMA principles. We examined data from 26 carefully chosen studies on MR, VR, and AR. At first, 96 pertinent papers were found by searching several databases, including ResearchGate, IEEE, PubMed, and others. 26 studies passed the screening process and were included in the final analysis. Key findings included:

- Performance: STEM competency, skill acquisition, and information retention were all enhanced by immersive technologies.
- Engagement: A rise in student involvement and enthusiasm for STEM education.
- Problem-solving: improved ability to solve problems in the actual world.

- Cognitive Load: Less cognitive load means it's easier to understand complicated STEM concepts.

The review emphasizes how AR and VR can improve student engagement, academic achievement, and transferable skills in STEM education.

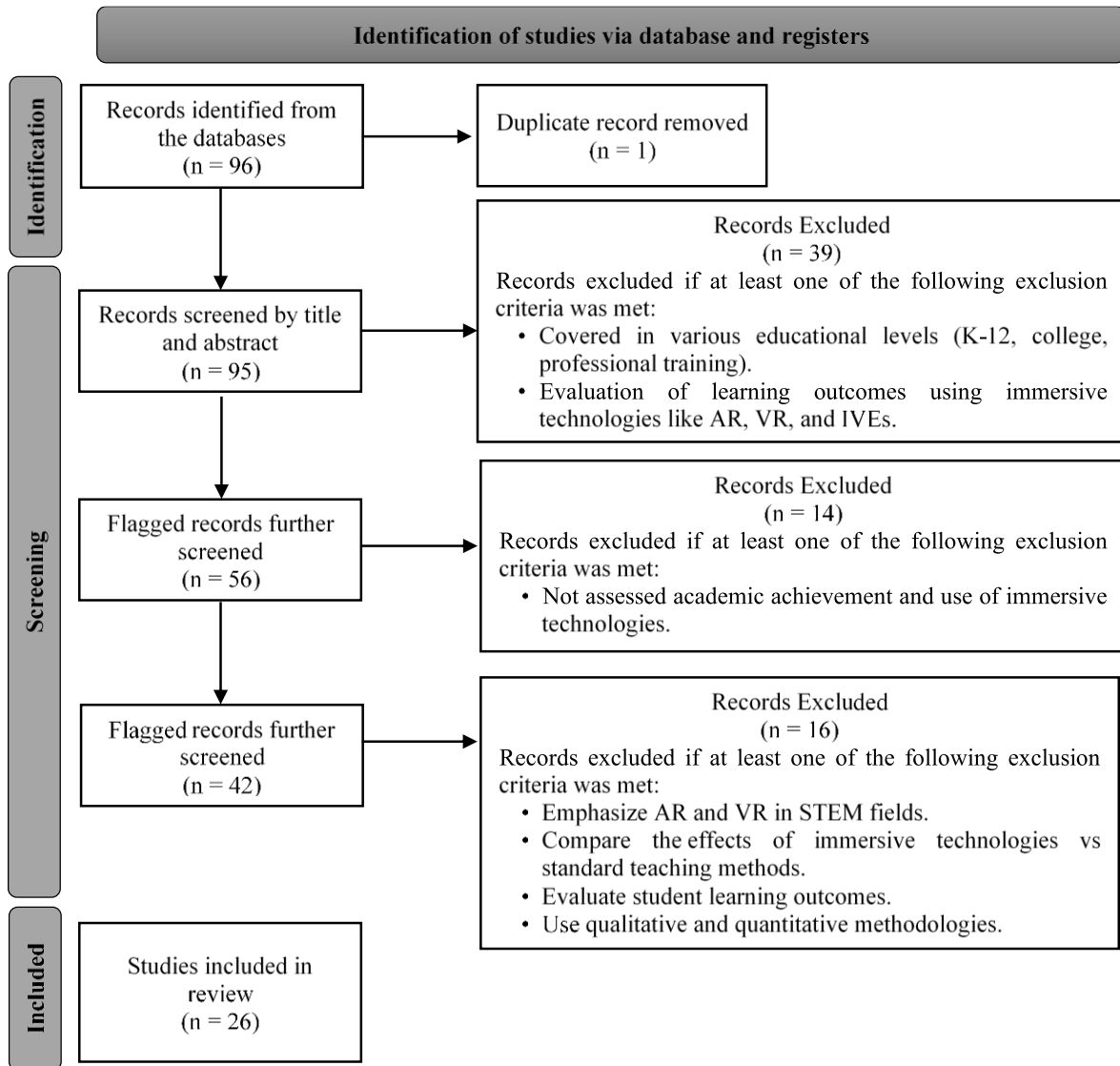


Figure 1: Flow chart of the systematic review

## 4.1 Data Analysis

**Table 2: Structural elements extracted with corresponding interventions and observed effect.**

Stage	Intervention	Variable	Effect	IVT	No. participants	References
<b>Development and Evaluation</b>	Usability study to evaluate how effectively students could navigate a virtual environment and operate a virtual CNC machine using an Oculus Rift VR headset.	Engagement and Performance	Problem-solving skills and cognitive load	VR	No specified	Christian et al, 2017
<b>Evaluation</b>	Explored the impact of using immersive virtual reality (VR) in science learning simulations, comparing it to traditional desktop learning.	Engagement and Performance	Problem-solving skills and cognitive load	VR	52	Guido et al, 2019
<b>Development and Evaluation</b>	Compared the effectiveness of two educational technologies, mobile-based (MB) and virtual reality (VR), with traditional teaching methods (textbook and lab work) for chemistry education over 18 weeks.	Engagement and Performance	Problem-solving skills and cognitive load	VR	103	Eric Nersesian et al, 2019
<b>Evaluation</b>	Scoping review aimed to explore the use and effectiveness of virtual reality (VR) in STEM education.	Engagement	Cognitive load	VR	No specified	Nikolaos Pellas et al, 2020
<b>Development and Evaluation</b>	Evaluates how VR facilitates practical, collaborative, and problem-based learning, which enhances understanding of abstract STEM concepts.	Engagement	Cognitive load	VR	No specified	Jiayun Mo et al, 2023
<b>Evaluation</b>	Identified relevant literature through a search of seven major online research databases related to education and technology.	Engagement	Cognitive load	AR	No specified	Maria et al, 2018
<b>Development</b>	Presents a novel approach to achieving multi-sensory learning by integrating virtual and augmented reality (VR/AR) with haptic wearables in STEM education.	Engagement	Problem-solving skills and cognitive load	VR/AR	No specified	Sanfilippo et al., 2022
<b>Evaluation</b>	Follows a pre-registered search strategy and screening process, which is available on the Open Science Framework (OSF)1.	Engagement	Problem-solving skills and cognitive load	VR	No specified	Alyssa Lawson et al, 2024
<b>Evaluation</b>	Examines experimental studies published since 2013, comparing quantitative learning outcomes using HMD-based I-VR to less immersive methods, such as desktop computers and slideshows.	Performance	Problem-solving skills and cognitive load	VR	No specified	D.Hamilton et al, 2020
<b>Development and Evaluation</b>	Developed the VR Multisensory Classroom (VRMC), an immersive learning environment delivered through a VR head-mounted display.	Engagement and Performance	Problem-solving skills and cognitive load	VR	No specified	Edwards et al., 2018

<b>Development and Evaluation</b>	Involved students engaging with an educational VR experience featuring an immersive narrative centered on a significant historical moment during World War II.	Engagement and Performance	Problem-solving skills and cognitive load	VR	120	James Calvert et al, 2020
<b>Development and Evaluation</b>	Investigate the effectiveness of Immersive Virtual Reality (IVR) as a tool for enhancing problem-solving skills in children aged 7 to 9.	Engagement and Performance	Problem-solving skills and cognitive load	VR	No specified	Araiza-Alba et al., 2021
<b>Development and Evaluation</b>	Evaluate the effectiveness of various virtual reality (VR) technology-based instructional approaches—specifically games, simulations, and virtual worlds—on learning outcomes in K-12 and higher education settings.	Engagement and Performance	Problem-solving skills and cognitive load	Games/ Simulations/ Virtual Worlds	8,432	Merchant et al., 2014
<b>Evaluation</b>	Effectiveness of virtual reality (VR) technology in educational contexts compared to traditional learning methods and passive video instruction.	Engagement and Performance	Problem-solving skills and cognitive load	VR	99	Devon Allcoat et al, 2018
<b>Evaluation</b>	Emphasizing the complex interplay of various factors that enhance learning through desktop VR.	Engagement and Performance	Problem-solving skills and cognitive load	VR	232	Ai-Lim Lee et al., 2010
<b>Development and Evaluation</b>	Emphasizing the importance of examining cognitive strategies in science education and providing evidence that is immersive and interactive.	Engagement and Performance	Problem-solving skills and cognitive load	VR	100	Richard et al, 2018
<b>Development and Evaluation</b>	Illuminate the current state of VR application in higher education, highlight gaps in research and practice, and advocate for further exploration of VR design and its implications for learning outcomes.	Performance	Problem-solving skills and cognitive load	VR	No specified	Jaziar Radianti et al, 2020
<b>Evaluation</b>	Demonstrate the effectiveness of iVR simulations in improving student learning in environmental biology compared to video viewing, emphasizing the potential of immersive technologies in education.	Engagement and Performance	Problem-solving skills and cognitive load	VR	28	Pande et al., 2021
<b>Development and Evaluation</b>	Convey the potential of an IVR application to improve STEM education by engaging students in an interactive and immersive learning environment, underpinned by cognitive and pedagogical frameworks.	Engagement and Performance	Problem-solving skills and cognitive load	VR	8	Acevedo et al., 2024
<b>Development and Evaluation</b>	Investigates the role of virtual reality (VR) in enhancing educational experiences, specifically focusing on the differences between immersive VR	Engagement and Performance	Cognitive load	VR	104	Makransky & Lilleholt, 2018

	and desktop VR in administering a virtual science learning simulation.					
<b>Development and Evaluation</b>	Investigates the effectiveness of immersive virtual reality (IVR) in enhancing student performance in STEM (science, technology, engineering, mathematics) education, specifically within the context of organic chemistry.	Engagement and Performance	Cognitive load	VR	224	Miller et al., 2021
<b>Development and Evaluation</b>	Investigates the effectiveness of a scaffolded Game-Based Learning (GBL) science unit incorporating a virtual reality (VR) game component to enhance secondary science students' understanding of scientific concepts.	Engagement and Performance	Cognitive load	VR	86	Ai-Chu et al, 2024
<b>Development and Evaluation</b>	Explores the use of virtual reality (VR) in STEM education, specifically focusing on how VR field trips can enhance learners' sense of presence.	Engagement and Performance	Problem-solving Skills and Cognitive load	Interactive Graphical Environments	30	Eileen et al, 2024
<b>Evaluation</b>	Study focused on the educational applications of Augmented Reality (AR) and Virtual Reality (VR).	Engagement and Performance	Problem-solving skills and Cognitive load	AR/VR	No specified	Mohamed Algerafi et al, 2023
<b>Development and Evaluation</b>	Focused on developing and evaluating a fully 3D-modeled immersive virtual reality (IVR) system designed to help primary school students learn about plants.	Engagement and Performance	Problem-solving skills and Cognitive load	VR	52	Cheng, 2023
<b>Evaluation</b>	Summarize a systematic review that investigates the integration of immersive technologies—specifically Virtual Reality (VR) and Augmented Reality (AR)—in STEM (Science, Technology, Engineering, and Mathematics) education.	Engagement and Performance	Problem-solving skills and cognitive load	AR/VR	No specified	Talia Tene et al, 2024

With an emphasis on the impacts of immersive technologies on performance, engagement, problem-solving abilities, and cognitive load, the analysis of the chosen research produced important conclusions about their application in STEM education. Nineteen (19.23%), five (19.23%), and three (7.69%) of the 26 papers that made up the review looked just at engagement, while the remaining five (19.08%) only looked at performance. This emphasizes how immersive technology might improve STEM learning outcomes in terms of cognitive engagement and academic achievement. 6 of the 20 studies (23.08%) particularly focused on cognitive stress, whereas the other six addressed problem-solving abilities and cognitive load in general. Studying problem-solving techniques alone was not the focus of any study. It would seem from this that although immersive technologies such as AR and VR can help lower cognitive load and make difficult STEM subjects easier to understand, their effects on problem-solving abilities have not received as much attention. The results highlight the wide range of applications of immersive technology in raising academic performance and point to the necessity of more study to improve students' capacity for problem-solving in authentic contexts.

## 5. Discussion

The use of IVT, particularly virtual reality, in STEM education has emerged as one of the most fascinating educational technologies because it creates a realistic and engaging learning environment. These major advantages can be summed up as follows:

- Virtual reality (VR) has the potential to improve student motivation and engagement because technology creates appealing and immersive learning environments that spark and maintain students' interest. When students are engaged, they are more likely to actively participate in class activities (Guido, 2019; Christian et al., 2017).
- Because VR provides students with greater substance and ease of comprehension, students are able to understand STEM subjects even better due to the visualization function in the VR (Abd Majid, 2018).
- Increasing interest in STEM disciplines: By offering innovative and engaging learning opportunities, virtual reality (VR) can encourage students to choose professions in STEM domains (Hsu et al., 2019).
- The development of spatial reasoning skills is a crucial aspect of STEM areas, and virtual reality can aid students in acquiring these abilities.
- The provision of auditory, visual, and kinesthetic experiences in virtual reality (VR) enables a greater range of learning styles to be accommodated.
- Virtual reality (VR) offers a safe and regulated means for students to hone their talents without the dangers or limitations of real-world settings.
- Flexible learning opportunities: Virtual reality (VR) can let students learn from anywhere, which is very helpful for distance learning.
- Assistance for teacher education: According to Lasica et al. (2020), VR can be utilized to increase teachers' professional development and capacity to instruct STEM courses.
- VR could foster imaginative and critical thinking according to Jesionkowska et al. (2020) who propose the integration of arts into STEM (STEAM).

### 5.1 Comparison with Previous Reviews

This study differs significantly from other reviews in a number of important areas:

- With an emphasis on incorporating metaverses into STEM education, Solanes et al. (2023) show how this might boost student involvement and teamwork. However, by investigating

more widespread VR applications in a variety of academic topics, such as STEM and the arts, this research goes beyond metaverses.

- In highlighting the value of virtual reality (VR) in cultural learning, Christopoulos et al. (2024) stress the importance of instructional design that is sensitive to context. By way of comparison, this study provides a broader outlook on virtual reality, which encompasses the customization of interventions for diverse learning environments.
- Günay and Barakat (2023) compare desktop VR with VR headsets and conclude that desktop VR is a more workable and affordable option. This study takes a different tack by underlining the significance of pedagogical design in virtual reality experiences, stressing that customized content—rather than the hardware platform—is more important in reaching educational objectives.

Building on previous research, this paper provides a more thorough and multidisciplinary investigation of the educational applications of virtual reality. It highlights the importance of accessibility, customization, and the range of applications and effects of virtual reality. This work is positioned as a crucial resource for future research as well as the wider application of virtual reality in education because of its creative methodology.

## 6. Conclusion

Through more dynamic, interesting, and productive learning opportunities, immersive technologies have the potential to revolutionize STEM education, as this evaluation demonstrates. Students may study difficult ideas in immersive settings that encourage greater comprehension and memory of the material thanks to the special possibilities that AR and VR provide for bridging the theory-practice divide. The benefits of immersive technology are evident, even though there are still issues, especially with regard to cost and teacher preparation. In order to shape STEM education going forward and equip students for success in the twenty-first-century workforce, these tools will become more and more crucial as they develop.

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