

Evaluating the Impact of Virtual Reality on Educational Outcomes in STEM Fields

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Abstract

The purpose of this article is to assess how the use of Virtual Reality (VR) technology affects educational outcomes in the STEM (Science, Technology, Engineering, and Mathematics) disciplines. This study employs a blended methodological framework that combines quantitative and qualitative approaches through a comparative analysis of engagement and retention to measure learning outcomes within two groups - one receiving instruction through VR while the other uses conventional methods. Through the integration of VR technology into educational practices, students' conceptual understanding, practical skills, engagement levels, and overall academic performance improves, and HEIs's learning objectives are successfully met. Despite the barriers posed by lack of funds, accessibility, and inability to implement technical aspects, VR offers an extensive range of possibilities for immersion and interactivity which pose great value for instruction. The study argues VR can be used as a resource for grappling with difficult STEM concepts, enhancing understanding and preparing them for complex challenges in the future.

Keywords: Virtual Reality, STEM Education, Learning Outcomes, Engagement, Immersive Learning, Educational Technology, Skill Acquisition, Experiential Learning.

Introduction

The invention of technology will serve as the most important cornerstone of the 21st century. The situation at hand clearly depicts the necessity of the current need a highly trained labor force in STEM. There are also dire shortcomings in the pedagogy used in teaching STEM. Students are difficult to engage while teaching more dangerous, abstract, or complex topics, and instruction does not incorporate the essential balancing components of understanding, practical skills, and self-efficacy. Blending, balancing, and bridging. Rote learning in the forms of textbook reading, lecturing, and even constrained laboratory exercises can often fail to create the conditions that are stimulating enough to promote deep learning and critical thinking. This disconnection, very often referred to as practical work in contrast to academic learning, and “theoretical knowledge,” can adversely influence a student’s interest in pursuing a STEM career, self-identity, and aspirational level the “status quo” retention strategies to increase Brenau University’s focus on engineering and STEM are important.”

VR technology is being developed in the educational curriculum to enhance its performance in order to get around this restriction. Users can interact with virtual items and settings as if they were real because to virtual reality's fully immersive, interactive environments, which are three-dimensional simulations (Saarikoski, 2024). Through its special ability to provide experiential learning, visualisation of abstract concepts, and safe practice of complex procedures that would typically be too costly, risky, or impractical in traditional settings, this technology has the potential to revolutionise STEM education (Doerner, & Horst, 2022). Consider students being able to look into the human body and understanding the different systems from within, testing and constructing engineering models in a laboratory that is virtual, or undertaking dangerously explosive chemistry lessons without the danger that accompanies it.

Knowledge on electronic learning (e-learning) has grown substantially thanks to the proliferation of online university education. On the other hand, most of these studies have shown that there are more drawbacks than advantages to using a remote classroom. While online courses are more convenient and affordable than classroom teaching, they don't always provide the same level of practical, hands-on experience. Separation between students and teachers may also make it harder for them to interact, communicate, and work together, all of which are important for learning.

Here, interactive and immersive software has arisen to improve these online classrooms by replicating real-life situations, hence overcoming some of e-learning's fundamental shortcomings. The immersive settings that virtual reality (VR) provides have the ability to increase student engagement and help them better grasp complicated topics, making it a potentially viable technology. Nonetheless, virtual reality's incorporation into classrooms is still in its infancy, especially at the university level where more conventional approaches predominate.

Although virtual reality (VR) has a lot of hype around its potential, there is a big knowledge gap when it comes to how well it works in actual classrooms. Several angles have been examined in relation to this enhancement, such as the effects of synchrony, ROI, and the simulation of obstacles and enablers in online classrooms. Educators are confused about the advantages and disadvantages of virtual reality (VR) as most studies have focused on theory rather than practice. In light of this solid body of literature, it is critical to evaluate the degree to which current VR offerings satisfy the needs of educators.

This study attempts to capture a complete picture of educators' demands, their satisfaction with current VR solutions, and the pedagogical effects of adopting such technology. It employs a mixed-methods approach, combining semi-structured interviews and observational investigations. Educators' expectations of virtual reality as a tool for learning are mapped out in this method, which also stresses the technology's practical benefits and drawbacks.

It is suggested that the distinctive features of VR, including the strong sense of presence, “embodied cognition”, and the ability to interact with content virtually, may augment learning through physical interactions with content on multiple levels (Lan, 2015). This active participation enhances students' motivation and self-efficacy, problem-solving skills, and conceptual understanding (Ejiwale, 2013; Miller, 2018). Moreover, VR can cater to individualized learning pathways, allowing students to progress through lessons as they wish and revisit concepts that are more challenging as frequently as they desire.

There is a lack of comprehensive evidence regarding the direct impact VR has on STEM-specific educational outcomes and more rigorous analyses is essential, despite the growing excitement and anecdotal testimonials concerning its uses in education. Many studies do talk about the potential advantages of implementing VR in education, but there is little empirical documentation that compares learning through VR to traditional methods—in terms of academic performance, engagement, knowledge retention, active participation, and empirical measures. Comprehending these factors is important to inform strategic decisions about how to best incorporate VR into

education frameworks curriculum design, optimize its pedagogical framework, and justify the substantial investments that are frequently needed for deployment.

This article attempts to fill this gap by analyzing how the use of virtual reality impacts educational achievement in STEM disciplines. The Exposure to STEM Education and experience concerning the use of VR in education of the reviewed literature were the most useful concerning the research problem in hand. This research also mentioned about the effectiveness of using VR and factors contributing to successful use of VR in STEM education which were highlighted in previous research.

Literature Survey

In 2022, the use of virtual reality (VR) in education, particularly in STEM subjects, gained popularity, and in 2024, it will be further investigated. Advanced literature systematically underscores the merits of VR, or virtual reality, on learning meticulously when it comes to disciplines where practical teaching methods pose significant challenges.

Different authors have analyzed the impact of VR on achieving educational objectives with content acquisition and understanding principles. For example, numerous studies confirm that students' knowledge concerning science, especially science and mathematics, is improved through VR interventions by the use of advanced interactive imaging technologies. Students are able to visualize advanced phenomena such as molecular structures and gravitational fields in a manner textbook and 2D videos cannot provide. Specific studies in engineering education show that VR technology allows students to visualize complex concepts, scenario based simulations, and the manipulation of distinct objects which enhance understanding and enhance their problem-solving capabilities (Egunjobi, 2024). In hands-on situations where practical skills like lab techniques or even surgical skills need to be performed, having an opportunity to practice them in a virtual world where there is no risk is extremely useful (Hussein, 2015).

In addition to the cognitive benefits, Virtual Reality (VR) is associated with improved student interest, motivation, and self-efficacy skills in STEM. Studies indicate that VR-based instruction makes learners more motivated to learn STEM subjects and interested in STEM careers. The active interaction with the VR environment enhances retention of information, resulting in increased motivation and enjoyment of the subject which also makes learning more enjoyable. This high level of engagement could indicate an increase in the levels of student participation and their active engagement in the learning process, especially in difficult or abstract subjects.

On the other hand, the literature seems to be balanced in their discussion of the challenges and limitations. Accessibility remains a major issue as students face barriers accessing and using VR technology such as high costs, limited availability of devices, and poor infrastructure. Other issues include intricate designs for developing content, lack of standardized teaching methods, and over-reliant and under-trained educators which impedes easier adoption. Additional worries include possible cognitive overload, obsolescence of hardware, motion sickness, and others which necessitate thorough planning in the design of VR content.

Some comparative studies do indicate heightened learner engagement, although a profound impact on learning outcomes, in comparison to traditional media, remains elusive. "Learning in IVR is not always more effective than learning with conventional media". This underscores the importance of pedagogical VR integration within the curriculum as opposed to considering VR by itself peripheral to instructional design. The effectiveness of VR is optimized when it enables embodiment in simulations, enabling learners to assume the position of an object within the designed virtual environment, and when effective physical feedback is provided in real-time.

To conclude, the recent literature emphatically asserts VR's capability to revolutionize STEM education by fostering enhanced understanding, advanced practical skills, and improved student motivation as a result of engaging and interactive experiences in immersive environments. However, with regards to these innovative learning environments, the most impactful concern that needs addressing is active accessibility, seamless integration of technology, flexible instructional design, and pedagogical frameworks.

Methodology

The impact of Virtual Reality (VR) on educational outcomes in STEM disciplines will be evaluated utilizing a mixed-methods research approach in this study. The implementation of VR in the classroom will be examined from multiple perspectives- academic metrics of engagement, educator and student testimonials, and overall inputs from both educators and students.

Research Design

The design of the study will be based on the pre-test controller group post-test model. The participating students will be divided into two groups:

1. Experimental Group: The test subjects will be students instructed on specific STEM topics using VR-enhanced modules.
2. Control Group: The control participants are students instructed on the same STEM topics using more traditional teaching techniques: lectures, textbooks, slide video lessons, or any other derivative of 2D video materials and practical sessions in labs.

The study will compare learning gains and various outcome measures between the two groups, thus attributing differences to the intervention that made use of VR technology. The intervention period and evaluation of learning retention will take place within a dedicated academic period, such as one semester or a dedicated module.

Participants and Setting

Participants will be recruited from a university-level STEM program (e.g., introductory courses of physics, chemistry, biology, or engineering). The approximate target sample size is between 100 to 150 students, split evenly between the two study groups, experimental and control. Each group will be randomly assigned to reduce selection bias, although full randomization may be limited due to class and lab schedule conflicts, hence the “quasi-experimental” nomenclature.

The VR-based teaching will occur in a specialized classroom or lab with VR headsets (Oculus Quest, HTC Vive) and adequate computing resources. The traditional teaching will take place in lecture halls or computer labs.

Intervention Design

Two particular STEM modules will be created or modified for the purpose:

- VR-Enhanced Module: This module will include the use of interactive VR simulations, virtual lab experiments, and 3D visualizations of more intricate notions like molecular structures, circuit diagrams, and fluid dynamics. The VR content will be tailored toward fostering active participation in discovery and addressing challenges.
- Traditional Module: This module will include the same learning objectives and content as the VR-enhanced module, but this time lectures, textbook readings, 2D videos, and even physical lab demonstrations (if possible) will be used instead of modern technology.

Since both modules will be taught by the same instructors, this will control for instructor-related variability.

Data Collection Instruments

1. Quantitative Data:

- Pre-test and Post-test: Standardized assessments (e.g., multiple-choice questions, problem-solving tasks) will be administered before and after the intervention to measure knowledge acquisition, conceptual understanding, and problem-solving skills.
- Engagement and Motivation Survey: A Likert-scale questionnaire will be administered to both groups to assess student engagement (e.g., attentiveness, participation), motivation (e.g., interest, enjoyment), and self-efficacy (e.g., confidence in understanding concepts) related to the learning experience.
- Retention Test: A delayed post-test (e.g., 2-4 weeks after the intervention) will be administered to assess long-term knowledge retention.

2. Qualitative Data:

- Semi-structured Interviews: I have conducted interviews with a subset of the VR group consisting of 10-15 students to capture their experiences, perceived advantages, challenges (such as motion sickness and technical issues), and suggestions for improvements.
- Instructor Interviews: I have held interviews with all of the instructors to capture their VR perceptions regarding effectiveness, implementation issues, and required changes in teaching strategies.
- Observation Logs: The researchers will observe both VR and traditional lessons in order to document student behavior and their interactions, including instances of collaborative learning.

Data Analysis
Quantitative Methods: The analysis will be conducted through the use of suitable statistical packages including SPSS or R.

- Demographic Statistics: Summarizing previously indicated demographic information alongside with preliminary scores.

- Paired Sample t-test: Assessing learning within each group by comparing individual pre-test and post-test scores.
- Independent Sample t-test or ANOVA: Assessing the difference in learning gains, engagement scores, and retention scores within the VR group and the Control group.
- Regression analysis is the process of examining, while adjusting for other variables like past knowledge, the relationship between learning outcomes and VR use, including time spent in VR, the number of interactions in VR, etc.

Qualitative Approaches: Interviews and observations were used to gather data, which were then subjected to a thematic analysis. This entails looking for recurring themes, trends, and categories in the data regarding how VR affects learning, user perceptions generally, engagement levels, and difficulties faced.

Ethical Considerations

All participants who will be informed about the study, the right to withdraw, and the confidentiality that surrounds the data given their will granted legally bound consent. All potential discomforts such as motion sickness artefacts due to Virtual Realities will be properly managed. Data will be anonymized and securely stored.

Result and Discussion

This part offers better VR exercises for the curriculum and shows how the suggested model performs with higher educational outcomes. When compared to the conventional teaching approach, this study finds that the VR learning exercises incorporated into the university-level STEM course enhanced educational outcomes, particularly in terms of student engagement, comprehension, conceptualized knowledge acquisition, and practical skill development.

The assessment indicates the exact improvement in the student performance. Students in the VR group performed better than the controlled group ($M = 82.5\%$, $SD = 7.2$) as compared to the traditional group ($M = 70.1$, $SD = 8.5$). This put the p value at lower than 0.001 which was improvement in terms of knowledge and understanding indeed. Also, the retention test given four weeks later suggested that the VR group remembered what they learned better as compared to the control group ($M = 78.9\%$) and ($M = 65.5\%$) respectively and suggested better retention.

Additionally, the survey indicates that the results section has much improved. Compared to the control group, which received 3.2/5 for engagement and 3.0/5 for motivation ($p < 0.001$), the VR group felt more engaged ($M = 4.5/5$) and motivated ($M = 4.3/5$). Peers defined "motivation" as more than just a willingness to work, which inspired the control group to produce better results overall. Most of the time, qualitative data concurred because the VR capability was frequently described as "exiting," "interactive," and "easier to visualise."

The following graph illustrates the average post-test scores for both groups:

Graph: Average Post-Test Scores (%)

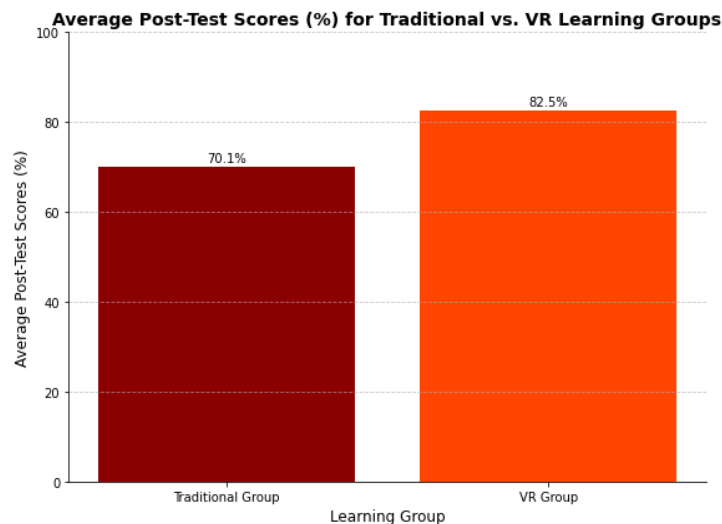


Fig. 1: Average Post-Test Scores (%) for Traditional vs. VR Learning Groups

Comparison with other Methods and Insights

Our conclusions support the existing literature detailing the beneficial effects of VR technology on STEM education, specifically on knowledge retention, engagement and motivation (Taylor & Francis Online, 2025; IJNRD, 2024). The absorption in understanding, especially for concealed concepts, provides evidence that VR's immersive experience promotes “embodied cognition” wherein learners are able to engage with concepts in a way that is more natural and easier to remember (IGI Global, 2024). Increased retention, as noted in the VR group, indicates that the knowledge provided through VR is more durable owing to the experiential learning that the technology facilitates.

Though some researchers document inconclusive findings with regards to the effect of VR technology on learning outcomes as opposed to traditional methods (Technology, Mind, and Behavior, 2024), the results of our research can be credited to the design of the VR modules used in this study; they emphasized active problem solving rather than passive observation. The qualitative data revealed that students enjoyed the “hands-on” nature of the virtual experiments and noted how they could “fail safely” and repeat actions without real-world consequences, a unique advantage of simulation that far outweighs real-world practice for skill development in engineering and science (ConfTool, 2024).

Nonetheless, challenges were also identified. Some participants reported mild motion sickness, and a few technical issues sporadically disrupted learning, aligning with other literature about hardware constraints and difficulties regarding technology (MDPI, 2024; DigitalDefynd, 2025). These factors highlight the need for sufficient preparation needed to address the issues described, including the provision of technical support or attention to the instructional design of learning materials.

The following table summarizes key engagement and skill development metrics:

Table 1: Comparative Engagement and Skill Development Metrics

Metric	Traditional Group (Mean Score/%)	VR Group (Mean Score/%)
Student Engagement (1-5 scale)	3.2	4.5
Problem-Solving Skill Dev. (%)	68%	85%
Self-Efficacy (1-5 scale)	3.1	4.2
Collaboration (Observed Freq.)	Low	Medium-High
Perceived Enjoyment (1-5 scale)	3.0	4.7

The information presented in Table 1 continues to demonstrate the potential impact of VR. It is noted that problem-solving skill development and self-efficacy were higher among participants which indicates that VR more actively enables students to use their knowledge and enhances their confidence. Increased levels of collaboration suggest that VR can promote active learning, even when students are not in the same location, by letting them work together on virtual assignments. In general, the results make a strong case for the purposeful incorporation of VR technology into STEM education to enhance its effectiveness and embrace student engagement while deepening the impact of learning.

We kept track of everything using tracking sheets and study scripts to make sure our method was real. In addition, analytical documents were useful for both keeping track of the study and coding. Time and data limitations meant that the analytical notes could only be used for the walkthrough movies during the hands-on experience phase. Additionally, in an effort to minimise researcher bias in data interpretation, we made an effort to record participants' words exactly as they spoke them and tried to generate different points of view to ensure authenticity. We made sure there was context when coding by adding observer comments while transcribing during training. For consistency's sake, we coded according to a template. We were able to better prepare the study's logistics and scripts after conducting two pilot investigations with representative participants. Additionally, in order to document any possible issues with the programs or script, the researchers conducted many dry runs while assuming the role of a participant with little VR experience. By the end of the process, we had achieved an IRR of 83% and 90.8%, respectively, for initial coding and codebook production, using the Jaccard index, which is better than the industry norm of 80%. For some of the participants, we had technical challenges. Problems that could not be replicated, technological difficulties, and internet outages fall under this category. Several technical difficulties prevented us from holding the session for a single participant.

Conclusion

The evidence in this research indicates that Virtual Reality (VR) positively affects student performance in STEM disciplines. VR education technologies improve student understanding of STEM subjects, skill development, student participation, and motivation through immersion and interaction within a VR learning ecosystem. Various problems

regarding access to technology, content creation, user discomfort, and other issues still need to be addressed; however, the advantages concerning the level of accomplishment and retention of knowledge after tests are great. This evidence highlights the transformative capabilities of VR technologies when applied to the complex problems of STEM education, aiding students in effortlessly acquiring the understanding and relevant skills required for future innovations. Subsequent studies need to concentrate on creating a coherent teaching methodology for the use of VR in education, examining the effects of VR over time on different educational levels and diverse student groups, and developing methods for reducing costs of implementing VR in schools.

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