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Enhancing Conceptual Understanding of Electricity and Magnetism through VR Simulations

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ABSTRACT: The study explores the efficacy of Virtual Reality (VR) simulations in enhancing students' conceptual understanding of electricity and magnetism, using the Labster platform. Traditional teaching methods often need to adequately convey the complexities of these topics, leading to limited student engagement and poor comprehension. The research compares two groups: one receiving traditional instruction and another using VR-based simulations. The study found that students in the experimental group, who used VR simulations, showed a 35% improvement in post-test scores, compared to a 15% improvement in the control group. The VR group also reported higher levels of engagement and found abstract concepts such as electric fields and circuits easier to understand through interactive, immersive learning environments. Teachers noted that VR aided in visualizing difficult concepts, although challenges included a learning curve in technology usage and the need for proper integration into curriculum. The findings suggest that VR, when used as a supplemental tool, has the potential to significantly improve learning outcomes in physics education. However, the study highlights the need for further research into long-term impacts and accessibility issues and strategies to better integrate VR into traditional teaching methods.

KEYWORDS: Electricity, Labster Simulations, Magnetism, Physics Education, Virtual Reality.

1. INTRODUCTION

1.1 Background of the Study

Physics education has consistently posed challenges in effectively conveying complex and abstract concepts, particularly in topics such as electricity and magnetism (Serbanescu & Petre, 2019). These topics require a strong ability to visualize interactions that are not directly observable, such as electric fields, magnetic forces, and the behavior of circuits. Researchers like Kibar and Akkoyunlu (2014) argue that the traditional approaches of textbooks, lectures, and static 2D representations limit the visualization and comprehension of these concepts. They posit that such methods fail to provide students with the interactive learning experiences necessary for a deeper conceptual understanding.

However, there needs to be more debate among educators and researchers on how best to address these conceptual challenges. Hobson and Ghoshal (2016) advocate for integrating more hands-on experiments and inquiry-based learning activities to provide real-world context and improve student comprehension of complex ideas. They argue that when students actively engage in problem-solving and experimental activities, they can better relate theoretical physics concepts to practical applications. Despite this, many physics teachers face constraints like limited lab time, lack of resources, and the inherent dangers or complexities involved in creating certain experiments (i.e., electromagnetism experiments), which restrict the effectiveness of hands-on learning.

In contrast, other researchers propose technology-enhanced solutions. Martín-Gutiérrez et al. (2017) suggest that virtual environments and simulations can be an effective alternative for teaching difficult physics concepts that are hard to replicate in real-world labs. They emphasize the potential of technology, such as Augmented Reality (AR) and Virtual Reality (VR), to allow students to interact with physics phenomena in a visual and immersive manner. However, their work also acknowledges a challenge in the implementation of these technologies, as it requires not only hardware but also software that aligns well with curricular goals.

1.2 Statement of the Problem

Traditional teaching methods often fail to teach complex physics topics effectively, resulting in poor conceptual understanding and student engagement. This study aims to address the following issues:

1. To what extent do VR simulations, specifically using the Labster platform, improve students' conceptual understanding of electricity and magnetism compared to traditional teaching methods?
2. How does the incorporation of Labster VR simulations impact student engagement and their problem-solving abilities in the context of physics education?
3. What are the perceptions of both students and educators regarding the effectiveness and usability of Labster as a teaching tool for electricity and magnetism?

1.3 Research Objectives

The primary objectives of this study are to evaluate the effectiveness of Labster VR simulations in enhancing students' conceptual understanding of electricity and magnetism. Additionally, the study aims to analyze the impact of VR-based learning on student engagement and motivation in the subject of physics. Finally, the research seeks to gather feedback from both students and educators regarding the usability and perceived benefits of utilizing Labster as an instructional tool for teaching electricity and magnetism.

1.4 Significance of the Study

This study is significant in demonstrating the potential of Virtual Reality (VR) technology, specifically the Labster platform, to enhance physics education by making abstract concepts like electricity and magnetism more tangible and interactive. Through immersive 3D simulations, students can visualize and experiment with complex phenomena in real-time, improving both conceptual understanding and engagement. The findings will contribute to the growing literature on technology-enhanced learning, offering educators practical insights on how VR tools can be effectively integrated into physics curricula to improve learning outcomes. Additionally, the study's feedback from students and teachers will provide valuable perspectives on the usability and benefits of VR in classroom settings.

1.5 Scope and Limitations

The study is focused on the use of Labster VR simulations in teaching electricity and magnetism at the senior high school level. It will compare the outcomes of VR based instruction against traditional methods over a period of 4 weeks. Limitations include the availability of VR equipment and the potential learning curve associated with using the technology. The research focuses on comparing the learning outcomes of students exposed to VR-based instruction using the Labster platform with those taught through traditional methods such as lectures, textbooks, and hands-on laboratory activities. The study spans a period of four weeks, during which students' conceptual understanding, engagement, and motivation will be assessed. However, several limitations must be acknowledged. One key limitation is the availability of VR equipment, as not all schools may have the necessary hardware to fully implement VR-based learning. This could restrict the study's applicability to institutions with adequate resources. Additionally, there may be a learning curve associated with using VR technology, both for students and educators.

2. LITERATURE REVIEW

2.1 VR as a Solution in Physics Education

Virtual Reality (VR) has been posited as an innovative approach to address the limitations of traditional physics instruction. The immersive experience of VR allows students to explore complex concepts in an interactive 3D environment, providing opportunities for deeper understanding (Lau & Lee, 2016). In their research, Jena (2019) argues that VR can create a learner-centered environment that promotes engagement and critical thinking, particularly when studying abstract physics topics like electric and magnetic fields. This argument is grounded in the idea that VR simulations allow students to "see" invisible forces, manipulate variables in real time, and receive immediate feedback on their actions.

On the other hand, there is skepticism about the efficacy of VR as a replacement for traditional laboratory experiences. Makransky et al. (2019) argue that while VR can enhance the sense of presence and engagement, it does not automatically lead to better learning outcomes. They suggest that the novelty of VR can be distracting if not integrated effectively into pedagogical practices. This aligns with the findings of Radianti et al. (2020), who highlight the importance of designing VR experiences that balance interactivity with clear learning objectives to avoid cognitive overload. Their meta-analysis indicates that VR's effectiveness largely depends on how well it is implemented into the curriculum and its alignment with educational goals.

Despite these concerns, research by Parong and Mayer (2018) supports the idea that VR can significantly improve conceptual understanding when it is used as a supplementary tool rather than a standalone experience. They found that VR simulations, when combined with structured guidance and debriefing, resulted in better retention of information and higher test scores in scientific topics compared to traditional methods alone. This suggests that the key to VR's success in education lies in its integration with active learning and reflective discussions.

2.2 The Role of Labster in Physics Education

Labster has emerged as a prominent VR platform designed specifically for science education. It provides simulations for topics like electricity and magnetism that are known to be challenging for students. According to Makransky and Lilleholt (2018), Labster's immersive simulations enable students to visualize and interact with complex physical phenomena, such as electric circuits, field lines, and magnetic forces, in a way that traditional methods cannot. Their research shows that students who used Labster simulations demonstrated significant improvement in conceptual understanding and enjoyed a more engaging learning experience. However, the practical challenges of implementing Labster in the classroom are not negligible. Klingenberg et al. (2020) highlight that for VR simulations like those provided by Labster to be effective, teachers must be adequately trained to facilitate the experiences and seamlessly integrate them into their teaching practices. Moreover, their findings stress the need for reliable access to technology, which may only be feasible in some educational settings due to costs and resource limitations.

Despite these challenges, Chiu et al. (2020) provide evidence that Labster's VR simulations positively affect students' cognitive engagement, particularly in physics. Their study demonstrates that students who engaged with Labster simulations exhibited higher motivation to learn and better problem-solving skills, which translated into improved test scores. They argue that the opportunity to experiment in a risk-free environment, where students can repeatedly test hypotheses and receive instant feedback, is invaluable in fostering a deeper understanding of electricity and magnetism.

2.3 Argument for VR Integration in Physics Education

While traditionalists like Hobson and Ghoshal (2016) emphasize the value of real-world experimentation and hands-on learning, recent advancements in VR offer a compelling alternative that addresses both the conceptual challenges and practical limitations of traditional physics instruction. VR platforms like Labster provide unique opportunities for students to visualize and manipulate abstract physics concepts, which is particularly important in topics like electricity and magnetism where spatial and conceptual reasoning are critical (Martín-Gutiérrez et al., 2017).

Critics of VR, such as Makransky et al. (2019), caution that with proper integration into teaching practices, VR can enhance learning effectively. However, the growing body of evidence supporting VR's ability to enhance engagement, motivation, and conceptual understanding indicates that, when used strategically, it can be a powerful supplement to traditional teaching methods (Parong & Mayer, 2018). This study aims to build upon this existing research by evaluating the specific effects of Labster VR simulations on learning outcomes in secondary-level electricity and magnetism, examining both the cognitive and affective impacts on students and teachers alike.

2.4 Gaps in Existing Research

Existing research, such as the work by Martín-Gutiérrez et al. (2017), has demonstrated that VR can enhance students' ability to interact with and understand difficult physics concepts. However, studies often lack a focused investigation into specific areas of physics, particularly electricity and magnetism, which are known to be particularly challenging for students to grasp using traditional methods. Similarly, while Klingenberg et al. (2020) found that VR simulations significantly improved student engagement, their research did not specifically address how these tools impact learning outcomes in abstract topics like electromagnetic fields or circuits. Furthermore, the majority of the existing literature emphasizes the novelty of VR but fails to provide long-term studies that assess the sustained impact of VR learning on knowledge retention and continued student interest in the subject. Another significant gap lies in the evaluation of educators' perceptions of VR in the classroom. While some studies focus on student outcomes, few explore how teachers view the integration of VR technology into their teaching practices, particularly in resource-constrained environments where access to VR equipment may be limited. Chiu et al. (2020) suggest that teacher training and support are critical for the successful implementation of VR in education, but more research is needed to understand how to best facilitate this integration. Additionally, much of the research in this field focuses on post-secondary education, with limited studies conducted at the secondary school level, especially in subjects like General Physics II for Grade 12 students. Makransky et al. (2019) pointed out that while VR offers an engaging and immersive experience, its integration into secondary education, particularly in physics, needs further exploration to understand its effectiveness and practical challenges in real-world classrooms. Parong and Mayer (2018) also highlighted the need for further research into how VR simulations can be effectively combined with traditional teaching methods to maximize their educational value.

3. RESEARCH METHODOLOGY

3.1 Research Design

The study employs a quasi-experimental research design with a mixed-methods approach. This design is chosen to assess the comparative effectiveness of VR-based instruction using the Labster platform against traditional instructional methods. The quasi-experimental design is appropriate because it allows for the comparison of two groups—an experimental group that uses VR simulations and a control group that receives traditional instruction without the need for full randomization. The mixed-methods approach combines both quantitative and qualitative data collection, ensuring a comprehensive understanding of the intervention's impact on student learning outcomes and engagement. The study is conducted over a period of four weeks, during which the experimental group engages with VR-based simulations on specific physics topics, while the control group receives instruction through traditional methods, including lectures, textbooks, and hands-on lab activities. This approach allows for direct comparison between the two instructional strategies and the measurement of changes in conceptual understanding, engagement, and motivation.

3.2 Participants and Sampling

The study involves 60 Grade 12 students enrolled in a General Physics II course at a secondary school. The participants are selected through convenience sampling, as they are already enrolled in the course. However, random assignment to either the experimental or control group ensures that the two groups are comparable in terms of baseline knowledge and demographics, minimizing potential biases. The two separate classes, which are randomly assigned to one of two groups:

Experimental Group (n=30): Students in this group engage with VR-based simulations using Labster for topics related to electricity and magnetism.

Control Group (n=30): Students in this group receive traditional instruction, including lectures, textbooks, and hands-on laboratory activities.

3.3 Intervention: Labster VR Simulations

The intervention in this study is the use of the Labster VR platform to teach specific subtopics within the electricity and magnetism unit of the General Physics II curriculum. Labster offers immersive simulations that allow students to visualize and interact with complex physical phenomena in ways that are not possible with traditional method following subtopics are covered in the VR simulations:

Electric Fields: Students simulate electric field lines and explore the forces between charges. This helps them understand the interactions and relationships between charged particles.

Magnetism and Electromagnetic Induction: The simulation allows students to visualize magnetic fields generated by current-carrying wires, explore Faraday's law, and induce currents, which are often difficult to grasp through static textbook representations.

Circuit Building: Students create series and parallel circuits in the simulation environment. They can manipulate variables such as voltage, current, and resistance and observe real-time changes in the system.

3.4 Data Collection Instruments

To measure the effectiveness of the intervention, a variety of quantitative and qualitative data collection instruments are used:

1. Pre- and Post-Tests: Standardized tests on electricity and magnetism are administered to both the experimental and control groups before and after the intervention. These tests measure the students' conceptual understanding of the topics covered. The difference in scores between the pre- and post-tests will indicate the extent of learning gains in both groups.

2. Surveys and Classroom Observations: After the intervention, students' complete surveys to provide feedback on their experiences with the Labster VR simulations. The surveys focus on engagement, motivation, ease of use, and perceived impact on understanding. Additionally, classroom observations are conducted during the VR sessions to assess how students interact with the simulations and evaluate their engagement level and active participation.

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3. Teacher Interviews: Semi-structured interviews are conducted with the teachers of both the experimental and control groups. These interviews explore the teachers' perceptions of VR as an instructional tool, its integration into the physics curriculum, and any challenges they encountered during the implementation. Teacher feedback is critical to understanding the feasibility and practicality of using VR in a classroom setting.

3.5 Data Analysis

The data collected in this study will be analyzed using both quantitative and qualitative methods to provide a comprehensive evaluation of the intervention's effectiveness. For the quantitative data, pre- and post-test scores from both the experimental and control groups will be analyzed using statistical tests. Paired t-tests will be conducted to compare the pre-test and post-test scores within each group, allowing the researcher to assess the improvement in conceptual understanding of electricity and magnetism for each instructional method. Additionally, independent t-tests will be performed to compare the post-test scores between the two groups, determining whether the VR-based instruction using Labster produced significantly higher learning gains compared to traditional teaching methods.

The qualitative data, gathered through student surveys, classroom observations, and teacher interviews, will be analyzed using thematic analysis. This approach will involve identifying recurring themes related to student engagement, motivation, and the perceived benefits and challenges of using VR simulations. Themes such as the usability of the VR platform, the level of student interaction with the simulations, and teachers' views on the integration of VR into their teaching practices will be explored in depth. This qualitative analysis will complement the quantitative findings, offering insights into the experiences of both students and educators and providing a fuller understanding of the impact of the VR intervention on the learning environment. By combining these two forms of data analysis, the study aims to measure the effectiveness of VR-based instruction in improving learning outcomes and to gain a deeper understanding of its influence on student engagement and teacher perceptions. This mixed-methods approach ensures a well-rounded evaluation of both the cognitive and affective dimensions of learning in the context of physics education.

Chapter 4: Results and Findings

This chapter presents the findings of the study, focusing on the effectiveness of Labster VR simulations in enhancing students' conceptual understanding of electricity and magnetism. It includes quantitative results from pre-test and post-test scores, statistical analyses, and qualitative insights from student and teacher feedback regarding engagement, motivation, and usability. These findings are discussed in relation to existing literature.

4.1 Quantitative Findings

4.1.1 Improvement in Conceptual Understanding

The primary quantitative data collected for this study were pre-test and post-test scores from both the experimental (Labster VR) and control (traditional instruction) groups. Pre-test scores were collected before the intervention, while post-test scores were administered after the four-week instruction period.

Table 1: Pre-test and Post-test Scores for Experimental Group

	Mean Score	Standard Deviation (SD)
Pre-Test	34.71	5.51
Post- Test	45.71	4.56

The average pre-test score for the experimental group was 34.75 with a standard deviation (SD) of 5.51, while the average post-test score was 45.71 with an SD of 4.56. The data show a significant improvement in the experimental group's scores following the VR-based instruction, indicating that the use of Labster VR simulations enhanced students' understanding of electricity and magnetism concepts.

To determine the statistical significance of the difference between pre-test and post-test scores, a paired t-test was conducted. The test yielded a t-statistic of -9.69 with a p-value of 1.33e-10, which is highly significant ($p < 0.05$). This indicates that the VR-based instruction significantly improved students' performance in understanding electricity and magnetism compared to traditional teaching methods. This supports findings by Radianti et al. (2020), who concluded that immersive learning experiences in VR enhance students' conceptual grasp and retention.

A comparative analysis between the experimental and control groups showed a significant difference in post-test results. An independent t-test confirmed that students in the VR-based group exhibited higher conceptual gains than those in the traditional instruction group, which aligns with studies by Parong and Mayer (2018), who found that VR simulations, when used alongside traditional methods, enhance overall learning outcomes in STEM subjects.

4.2 Qualitative Findings

4.2.1 Student Engagement and Motivation

To supplement the quantitative data, qualitative feedback from both students and teachers was gathered through surveys and interviews. This section provides insights into the level of student engagement and motivation while using the Labster VR platform.

1. **Increased Engagement:**

   Students reported that VR simulations were far more engaging than traditional methods. They appreciated the interactive and immersive nature of the learning environment. One student mentioned, "S22: The VR made it feel like we were inside the simulation, which helped me focus more and better understand the material."

   S27 Feedback: "Mas interesado kami sa topic kapag may ganitong interactive na tools" (We were more interested in the topic when using interactive tools like these).

   S39 Feedback: "Mas sayon og mas lingaw ang pagkat-on sa mga complex topics" (It was easier and more fun to learn complex topics).

Research supports these findings, as interactive simulations have been shown to increase student engagement by providing a dynamic and hands-on approach to learning (Makransky et al., 2019; Martín-Gutiérrez et al., 2017). VR allows for an immersive experience that stimulates curiosity and engagement, allowing students to actively participate in their learning process (Radianti et al., 2020).

2. **Improved Visualization and Conceptual Understanding:**

   Students found that concepts like electric fields, electromagnetic induction, and circuit behaviors were easier to understand with the help of VR simulations. The ability to manipulate variables in real-time and receive immediate feedback was particularly beneficial for visualizing abstract concepts.

   S34 Feedback: "Nakakatulong yung VR para mas ma-visualize namin yung mga invisible forces, kasi sa libro minsan ang hirap intindihin" (VR helps us visualize invisible forces because it's sometimes hard to understand them through the book).

This aligns with previous research that highlights the importance of visualization tools in improving student understanding of abstract scientific concepts, especially in physics (Martín-Gutiérrez et al., 2017). As Jena (2019) noted, VR allows students to explore "invisible" forces in ways that are not possible through traditional teaching, promoting deeper conceptual understanding.

3. **Higher Motivation and Collaborative Learning:**

The VR simulations fostered collaboration among students. During classroom observations, students were seen working together to solve problems within the simulation, helping each other understand difficult concepts.

S41 Feedback: "We worked together in groups and helped each other understand what was happening in the simulation."

S56 Feedback: "Nakakaengganyo siyang gawin kasi parang hands-on na, tapos nakakatuwang magtulungan" (It's engaging because it feels hands-on, and it's enjoyable to work together).

Collaborative learning in VR environments has been linked to higher motivation and more profound conceptual understanding, as it encourages students to engage actively and work in teams (Makransky et al., 2019; Parong & Mayer, 2018). This is further supported by studies showing that collaboration in VR helps students build deeper connections to the material by fostering group problem-solving and discussion (Radianti et al., 2020).

4.2.2 Teacher Feedback

Teachers also provided valuable insights into the effectiveness of VR-based learning. According to one teacher, "The students were noticeably more engaged during the VR lessons compared to traditional lectures. They asked more questions and were eager to explore the simulations." Another teacher mentioned that while there was an initial learning curve in using the

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technology, students adapted quickly and showed increased interest in the subject matter. Research by Parong and Mayer (2018) supports this, as they found that VR simulations, when used alongside structured guidance and debriefing, lead to improved learning outcomes and greater student motivation. Teachers have also emphasized the role of VR in fostering active learning, noting that it allows students to experience scientific concepts interactively rather than passively receiving information.

4.3 Comparison Between Experimental and Control Groups

To further understand the effectiveness of VR simulations, the post-test results of the experimental group were compared to those of the control group, which received traditional instruction. While the control group also showed improvement, the gains were significantly smaller than those observed in the experimental group. The control group's pre-test average was approximately 35, and the post-test average improved to 40, compared to the experimental group's average improvement from 34.75 to 45.71.

Table 2: Comparison of Pre-Test and Post-Test Scores Between Experimental and Control Groups

Group	Pre-Test Mean	Post-Test Mean	Difference
Experimental Group	34.75	45.71	+10.96
Control Group	35.00	40.00	+5.00

An independent t-test confirmed the significant difference between the post-test scores of the experimental and control groups ($p < 0.05$), demonstrating that students in the VR-based group had greater conceptual gains than those who received traditional instruction. This mirrors findings from earlier studies (Makransky et al., 2019; Radianti et al., 2020), where VR-based learning consistently led to higher learning outcomes compared to traditional methods, particularly in STEM education.

5. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

5.1 Discussion

The results of this study strongly support the hypothesis that VR simulations enhance student learning in physics, particularly in challenging topics like electricity and magnetism. The significant improvements in post-test scores, combined with positive feedback from students and teachers, demonstrate that immersive learning environments provide a unique opportunity to overcome the limitations of traditional instruction.

This study's findings are consistent with existing literature, such as the work of Jena (2019), who found that VR promotes deeper understanding by allowing students to experiment and interact with abstract concepts in a hands-on manner. Additionally, the increased engagement and collaboration observed align with Makransky et al. (2019), who noted that VR's immersive nature enhances motivation and active participation in the learning process.

5.2 Conclusion

The use of Labster VR simulations significantly improved students' understanding of electricity and magnetism, as evidenced by both quantitative and qualitative data. The results suggest that VR technology can play a transformative role in physics education, offering students a more engaging and effective way to grasp complex scientific concepts. However, challenges such as the learning curve associated with new technology and access to VR equipment must be addressed to maximize the benefits of this approach in educational settings.

5.3 Recommendations

Based on the findings of this study, several recommendations can be made to enhance the use of Virtual Reality (VR) in secondary-level physics education, specifically in teaching abstract concepts such as electricity and magnetism:

1. Integration of VR as a Supplementary Tool: While VR has been shown to significantly improve conceptual understanding and student engagement, it should be used as a supplementary tool alongside traditional teaching methods rather than a standalone solution. Teachers should blend VR simulations with lectures, hands-on experiments, and guided discussions to maximize learning outcomes. This recommendation aligns with findings by Parong and Mayer (2018), who observed that students benefit most when VR is integrated with structured pedagogical strategies.
2. Teacher Training and Professional Development: To successfully implement VR technology in the classroom, teachers must receive proper training. Professional development programs should focus on helping educators understand the

pedagogical benefits of VR, how to navigate the technology effectively, and how to seamlessly integrate it into the curriculum. Studies by Makransky and Lilleholt (2019) highlight that teacher confidence in using VR tools is a crucial factor in the technology's success in the classroom.

3. Addressing Technological Barriers: While VR offers a transformative approach to teaching, accessibility remains a significant challenge, particularly in resource-constrained educational settings. Schools and policymakers should explore cost-effective options for acquiring VR equipment and providing adequate technological infrastructure. Additionally, partnerships with educational technology companies, like Labster, could be developed to ensure schools have access to affordable VR platforms.
4. Focus on Student-Centered Learning Approaches: Given VR's immersive and interactive nature, teachers should employ student-centered learning approaches that promote active learning and problem-solving. Encouraging collaborative activities within the VR simulations can further enhance engagement and deepen students' conceptual understanding, as noted in research by Radianti et al. (2020). Such methods can also stimulate critical thinking and foster a deeper connection to the material.
5. Further Research on Long-Term Impact: This study focused on the short-term effects of VR on learning outcomes over a four-week period. Future research should explore the long-term impact of VR-based instruction on knowledge retention, student interest in STEM fields, and continued engagement with physics concepts. Additionally, studies should investigate the scalability of VR in diverse educational contexts, including its effects on students with varying learning styles and abilities.
6. Developing Curriculum-Aligned VR Content: To ensure the maximum benefit of VR tools like Labster, it is important that VR content aligns closely with the educational curriculum and learning objectives. Collaboration between educational institutions, technology developers, and curriculum designers is essential for creating VR modules that meet the specific needs of secondary-level physics education. This will ensure that VR experiences are not only engaging but also relevant to the learning goals.

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