Impact of Virtual Reality on pre-university students

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Abstract: Integrating Virtual Reality (VR) into educational environments represents a significant advancement in teaching and learning. Traditional text-based instruction can diminish student engagement, while VR can fully immerse students, enhancing motivation, understanding, and participation. This study explores the impact of VR in education, highlighting its ability to engage students and improve information retention. However, challenges such as accessibility, cost-effectiveness, and safety need to be addressed. Student feedback highlighted VR's engaging and immersive nature but noted technical issues and a need for more diverse content. Recommendations for improvement include expanding content diversity, enhancing visual and audio quality, reducing equipment costs, and providing additional support for students with limited technology skills. Ultimately, VR shows great promise in transforming education by creating interactive and immersive learning experiences, with ongoing research and development being essential to fully realize its potential.

Keywords: Virtual Reality, VR Education, Student Engagement, Immersion, Innovation.

Impactul Realității Virtuale asupra elevilor

Rezumat: Integrarea realității virtuale în mediile educaționale reprezintă un progres semnificativ în predare și învățare. Instrucțiunile tradiționale bazate pe text pot diminua implicarea elevilor, în timp ce realitatea virtuală poate imersa complet elevii, sporind motivația, înțelegerea și participarea. Această lucrare explorează impactul realității virtuale în educație, subliniind capacitatea sa de a implica elevii și de a îmbunătăți reținerea informației. Cu toate acestea, provocări precum accesibilitatea, rentabilitatea și siguranța trebuie abordate. Feedbackul studenților a subliniat natura captivantă și imersivă a realității virtuale, dar a menționat probleme tehnice și necesitatea unui conținut mai diversificat. Recomandările pentru îmbunătățire includ extinderea diversității conținutului, îmbunătățirea calității vizuale și audio, reducerea costurilor echipamentelor și oferirea unui suport suplimentar pentru elevii cu abilități tehnologice limitate. În cele din urmă, realitatea virtuală prezintă un mare potențial în transformarea educației prin crearea unor experiențe de învățare interactive și imersive, cercetarea și dezvoltarea continuă fiind esențiale pentru realizarea deplină a acestui potențial.

Cuvinte cheie: realitate virtuală, educație VR, implicarea elevilor, imersiune, inovație.

1. Introduction

Virtual Reality (VR) is a cutting-edge development in computational design, relying on three-dimensional spatial concepts to fully engage users through auditory, visual, and interactive experiences. VR enables users’ interaction with virtual environments through intuitive interfaces (Lyu et al., 2023). VR's essential attributes include immersion, interactivity, and high engagement. Immersion refers to the state in which individuals lose awareness of their physical surroundings, becoming fully absorbed in virtual environments (Lyu et al., 2023). Interactivity involves the active exchange of information and participation in tasks within virtual environments, providing users with a sense of control and involvement (Lyu et al., 2023). VR uses Head-Mounted Displays (HMDs) to create immersive experiences. Equipped with motion sensors, high-resolution displays, and spatial audio, these HMDs achieve full immersion by tracking users' head movements and spatial positioning, seamlessly blending real with virtual (Muñoz-Saavedra, Miró-Amarante, Domínguez-Morales, 2020). In immersive settings, HMDs and controllers enable manipulation and interaction with virtual objects (Matovu et al., 2022). Integrating VR into educational frameworks allows for a dynamic, multimedia platform that enhances engagement and interactivity through text, sound, images, video clips, and animations in virtual spaces (Matovu et al., 2022). This technology offers students a broad range of learning opportunities through the use of displays, three-dimensional visuals, and spatial audio (Won et al., 2023). Although VR in education holds great

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potential, it also faces specific challenges that must be addressed before it can be successfully implemented. Personalized strategies are essential to promote significant knowledge retention and drive innovation in educational VR applications (Marougkas et al., 2024). Clear and precise instructions are essential, especially for beginners, to navigate virtual environments successfully (Marougkas et al., 2024). Additionally, resilience strategies, such as fostering digital literacy and critical thinking to counter misinformation (Zamfiroiu et al., 2024), may complement VR's role in enhancing educational outcomes. Collaboration between VR developers and educators is necessary to create high-quality educational materials that can be effectively utilized on VR platforms (Cowan & Farrell, 2023). To optimize student engagement and promote deep learning, it is critical to offer a diverse array of relevant and captivating content.

This study investigates the capacity of VR technology to revolutionize educational experiences by enhancing students' engagement, comprehension, and knowledge retention. As VR becomes increasingly integrated into educational frameworks, it offers a dynamic platform for immersive learning. Specifically, this research aims to evaluate how VR tools influence student engagement, comprehension, and overall academic performance in a pre-university classroom setting. To explore these objectives, a group of students accessed VR technology through a structured series of instructional applications. The study evaluated VR's influence on these students by administering pre- and post-interaction questionnaires, which assessed their initial familiarity with digital technologies, perceptions of VR's effectiveness as an educational tool, and any changes in their understanding and engagement with the subject matter. The key goals of the study are outlined in Table 1.

Table 1. Study key goals

Objective	**Observations**
Assess the Educational Impact of VR	Analyze the effect of VR tools on students' engagement, understanding, and overall learning experiences.
Analyze Student Engagement	Evaluate how VR applications, such as "First Steps" (Meta, 2019) and our educational application, improve student engagement and motivation.
Explore Student Perceptions	Examine students' attitudes toward VR technology before and after exposure, assessing changes in their comfort levels and perceptions
Evaluate Understanding of Educational Content	Assess the impact of VR on students' understanding of theoretical topics, with a focus on how VR improves knowledge retention.
Optimize VR Learning Sessions	Explore ways to optimize the effectiveness of VR learning sessions through student feedback and iterative improvement.

In this study, research questions are essential for guiding the investigation and obtaining answers relevant to the objectives. Therefore, we propose the following research questions to be addressed:

- **RQ1.** What impact does VR technology have on students' educational experiences?
- **RQ2.** What contribution do VR applications make to students' engagement in the learning process?
- **RQ3.** How do students perceive VR technology in an educational context?
- **RQ4.** What are the effects of using VR technology on the understanding of educational content?
- **RQ5.** How can learning sessions with VR technology be optimized in the context of education? - This question looks for ways to improve learning sessions while taking into account the input and outcomes from the study's use of VR technology.

This study's VR application, developed by using Unreal Engine's VR template, integrates dynamic components for an immersive educational experience. The user interaction system leverages Unreal Engine's input handling and control interfaces, enabling seamless navigation and object manipulation. Real-time physics simulation ensures realistic object behavior, creating a highly engaging experience. Custom object classes, like Selection 2, manage complex interactions, such as object identification and manipulation, enabling adaptive learning based on user actions. The VR application guides students through progressive learning stages: delivering educational content via 3D models, reinforcing understanding through task-based interaction, and advancing to complex topic exploration. This design encourages active participation and supports various cognitive stages, enhancing retention and comprehension. Together, these features provide an immersive learning experience that aligns with modern pedagogical approaches and supports the study objectives.

This article is organized into several sections to explore and detail the impact of VR in education. The Background and Theoretical Framework section reviews relevant literature and theories supporting the integration of VR in education. The Methodology section outlines the experimental design, tools used, and overall framework of the study. In Results, the collected data and statistical analyses are presented, highlighting the impact of VR on student engagement and comprehension. The Discussions section synthesizes the main findings and limitations of the study, while Conclusions and Future Work provide final remarks and propose future research directions, emphasizing the transformative potential of VR in education.

2. Background and theoretical framework

This section examines a series of case studies on VR use in diverse educational contexts. Each study is reviewed to uncover the data collection methods, specific technologies applied, educational strategies implemented, and resulting outcomes. This analysis aims to build a comprehensive understanding of VR integration in education, assessing its effectiveness as well as the challenges and opportunities that arise.

Studies by Larsen et al. (2023) and Huang et al. (2023) examined VR's educational impact and found no significant differences compared to traditional learning methods, suggesting that VR's benefits may vary based on specific scenarios and objectives. Expanding on this, Andersen, et al. (2023) demonstrated that fully virtual classes provide adaptable, self-guided learning experiences as effective as conventional teaching, supporting VR as a viable alternative for interactive learners. Shim (2023) found that VR enhances engagement, motivation, and creativity in moral education, though it should be used alongside traditional methods to fully develop students' moral reasoning. Additionally, Huang et al. (2023) emphasized the importance of designing VR applications that balance enjoyment with educational goals to ensure sustained user engagement.

In professional contexts, studies by Bakhoum et al. (2023) and Wolfartsberger et al. (2023) highlighted VR's potential to improve hands-on training and project management in fields like construction, demonstrating the impact of context-specific design on learning outcomes. The study by Darwish, Kamel & Assem (2023) found that Extended Reality (XR) enhances spatial reasoning and design skills in architecture education, while Omori et al. (2022) showed VR's effectiveness in healthcare training, particularly for improving infection control protocols.

VR broadly supports experiential learning, problem-solving, and collaboration, grounded in constructivist and experiential learning theories (Darwish, Kamel & Assem, 2023). Similar findings in military contexts show that VR's immersive capabilities improve decision-making and operational readiness through realistic training scenarios, demonstrating its effectiveness across diverse domains (Bucăța et al., 2023). It enhances retention and comprehension by creating immersive, realistic environments that facilitate situated learning (Elmqaddem, 2019; Cowan & Farrell, 2023). VR also fosters personalized learning, curiosity, and analytical thinking through interactive activities (Saunders et al., 2019; Wang et al., 2024). The methodology outlined by Try, et al. (2021) proposed a VR integration methodology involving goal-setting, application design, testing, and outcome evaluation, resulting in engaging, effective VR environments. Together, these studies (Andersen et al., 2023; Huang et al., 2023; Larsen et al., 2023; Shim, 2023;) showcase VR's versatility and effectiveness across various educational and professional domains. They highlight the importance of context, users' experience, and customized application design in maximizing VR's educational potential.

VR technology enables students to explore and learn across a wide range of academic subjects (Díaz, Saldaña & Ávila, 2020; Battal & Taşdelen, 2023). By facilitating immersive learning experiences, game-based VR environments allow students to assume identities in virtual worlds, offering unique educational opportunities across disciplines, including for students in remote settings (Díaz, Saldaña & Ávila, 2020; Battal & Taşdelen, 2023). Studies have also shown that VR can enhance user interaction and immersion through advanced simulation techniques, further broadening its educational potential (Marinescu & Iordache, 2023). When learners experience a smooth, high-quality immersive environment, VR can make learning impactful and sustainable. Virtual environments also promote curiosity-driven exploration and discovery (Xiangyu, 2019; Marougkas et al., 2023). Educational institutions can harness VR technology by establishing virtual laboratories, providing educators with new ways to deepen students' understanding of academic content. For example, Xiangyu (2019) analyzes the promotion conditions of "VR+education" where students can conduct geographical experiments (e.g., simulating earthquakes and volcanic eruptions), biological explorations (e.g., examining human anatomy), interact with literary content, and visualize historical figures. This virtual laboratory fosters novelty through space-time exploration and direct interaction, allowing students to experience simulated events in an engaging, highly interactive way.

The literature identifies several theories for analyzing VR's role in higher education, including motivational theory, connectivism, behaviorism, social cognitive theory, and motor learning theory (Bonner & Lege, 2020). These theories support the intrinsic motivation for adopting VR in educational contexts. A study by Bonner & Lege (2020) also highlighted three primary challenges in implementing VR in education: pedagogical gaps, cognitive demands, and immersion breakage. Radianti et al. (2020) further emphasized that, while VR can be effectively integrated into educational settings, it should be viewed as a distinct teaching method rather than a direct replication of traditional face-to-face instruction (Elmqaddem, 2019). Educators must design VR-based programs that are well-suited to this technology and aligned with the needs of 21st-century learners (Elmqaddem, 2019).

Strategic planning and collaboration are essential to maximizing VR's potential in education. Bloom's Taxonomy (Bloom, Krathwohl & Masia, 1984) provides a framework for classifying educational objectives, from basic knowledge recall to advanced cognitive skills like analysis and creation (Caratozzolo & Alvarez-Delgado, 2021). Integrating VR with Bloom's Taxonomy enables educators to guide students through progressively complex cognitive tasks, from recalling information to generating new knowledge in immersive settings (Hamilton et al., 2021; Fasihuddin, 2023). This alignment optimizes VR's educational impact by addressing both opportunities and challenges in modern learning environments. However, while VR's immersive nature is highly engaging, it can also overwhelm learners, especially when cognitive processing demands are high (Uriarte-Portillo et al., 2022). Students with a higher capacity for immersive learning often achieve better outcomes, yet excessive complexity in VR environments can hinder learning by overloading cognitive resources (Ghomi, 2018). The study by Caratozzolo & Alvarez-Delgado (2021) found that high cognitive loads can reduce knowledge retention, while issues like poor equipment quality or visual distortions can further reduce VR's effectiveness (López-Jiménez et al., 2021; Larsen et al., 2023).

Integrating VR into pre-university education presents challenges that must be addressed for successful implementation (Ghobadi & Sepasgozar, 2019; Jacqueline, 2023). Key issues include accessibility, cost, technical limitations, and content quality. Additionally, effective educator training and support are essential, as VR technology requires specialized knowledge and skills for classroom use. Student safety is also a priority, as VR may cause discomfort, such as motion sickness, and raises data privacy concerns. The literature highlights several critical challenges that must be addressed, including:

- Accessibility and Cost: Implementing VR technology requires significant investment in hardware, software, and infrastructure, posing financial challenges for many schools, particularly those in underfunded regions;
- Technical Obstacles and Infrastructure: Limited resources can lead to technical issues, such as delays, low graphics quality, and device malfunctions during VR sessions, which affect the learning experience negatively;

- Training and Support for Educators: Effective integration of VR in classrooms necessitates specialized training and ongoing support for educators;
- Content Variety and Quality: Developing high-quality VR content is labor-intensive and costly, potentially limiting VR's effective use in education;
- Student Safety: VR can cause physical discomfort, like motion sickness, and raises data privacy and security concerns. Prioritizing student safety and comfort is essential.

3. Methodology

VR technology is an innovative tool in modern education, capable of creating immersive and interactive learning environments that enhance students' educational experiences. It has the potential to transform traditional teaching methods, especially in pre-university settings, where active involvement and deep understanding are essential for academic success. By engaging students in three-dimensional simulations and virtual worlds, VR bridges theoretical knowledge with practical applications, making learning more engaging and effective. To align VR scenarios with Bloom's Taxonomy, we structured educational objectives across various levels of cognitive complexity. Bloom's Taxonomy provides a hierarchical framework that starts with memorization and progresses to advanced cognitive skills such as analysis, evaluation, and creation (Caratozzolo & Alvarez-Delgado, 2021).

This study used a single-group experimental design to evaluate the impact of VR technology on classroom instruction. Participants filled in questionnaires before and after the VR session, allowing us to monitor their progress and assess changes resulting from their engagement with the technology. The VR application was developed using Unreal Engine 5 (Unreal Engine) and packaged as an APK file. The installation process was completed using Meta Quest Link (Meta) and Meta Quest Developer Hub (Meta) applications, freeing users from the limitations of traditional computer-generated experiences. Hazardous waste management scenario was intentionally chosen for students aged 15 to 18 to align with their educational background. These students are enrolled in an Environmental Protection profile within the Natural Resources and Environmental Protection field, where hazardous waste management is part of the curriculum. Presenting this topic in a VR environment reinforces classroom learning with an immersive, practical experience. Given their prior familiarity with the subject, the VR scenario enhances understanding by offering an interactive, hands-on approach to a real-world environmental issue central to their studies.

The primary purpose of the questionnaires was to gather insights into students' perceptions and experiences with VR equipment. The questionnaires included four-level Likert scale questions addressing topics such as comfort in using VR, participation in virtual activities, and perceptions of the advantages and challenges of VR in the classroom. Before starting the practical exercises, students completed a pre-questionnaire with two sections: one assessing their level of digital literacy and another exploring their initial attitudes toward VR technology. Completing the pre-questionnaire was essential for several reasons:

- It provided a baseline measurement of students' familiarity with digital technologies.
- It allowed us to assess students' initial perceptions of VR as an educational tool.

To engage a broad range of cognitive skills, we aligned the VR scenario objectives with Bloom's Taxonomy. This encouraged critical thinking and knowledge application, particularly within the context of hazardous waste management. The VR educational scenario was structured into three distinct stages, each designed to serve a specific purpose in the hazardous waste management learning process:

- **Informing the learner through objects, images, and text:** The first phase of the application introduces essential concepts of hazardous waste management within an interactive virtual environment that combines visual and textual elements. This stage aims to build a solid knowledge base, preparing learners for the upcoming interactive activities that apply these concepts practically. In addition to 3D objects, the virtual environment includes text and static images illustrating various waste types (see Figure 1).

- **Task - identifying types of waste:** In this stage, learners apply the knowledge gained in the information phase by identifying and classifying various types of hazardous waste. This interactive task reinforces theoretical knowledge while offering a hands-on experience, allowing users to practice making quick and accurate decisions in waste management. The goal of this stage is for learners to review and apply their understand-ding by correctly identifying and categorizing hazardous waste types (see Figure 2).
- **Informing learners about batteries and accumulators:** In this stage, learners receive a detailed overview of batteries and accumulators, with an emphasis on the importance of proper waste management. The primary goal is to educate learners on the various types of batteries and accumulators, associated risks, correct disposal and recycling methods, and their environmental impact.

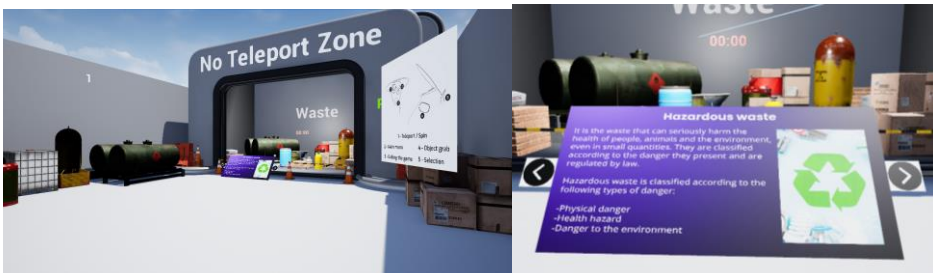

Figure 1. Informing the learner through objects, images, and text

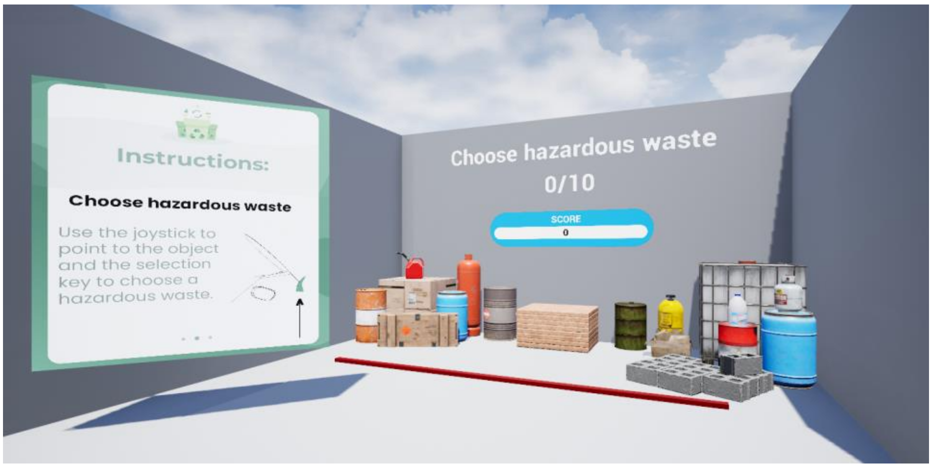

Figure 2. Task Identifying Types of Waste

Throughout the scenario, students earn points for correct answers, motivating ongoing participation and reinforcing learning. This gamification element not only adds an interactive layer to the experience but also helps students track their progress and stay engaged. Additionally, students can access previously displayed information, allowing them to revisit and review content as needed. This accessibility aids in consolidating their understanding, reinforcing key concepts, and supporting better retention. The development of VR educational scenarios is a collaborative, iterative process involving multiple contributors, each bringing specific expertise to ensure that the VR experience is both pedagogically sound and technically robust. This process unfolds in distinct phases, each focused on different aspects of development and implementation, from defining educational content to evaluating learning outcomes.

4. Results

A total of 21 students, aged 15 to 18 and enrolled in the environmental protection program, were introduced to VR through the "First Step" application (Meta, 2019), which provided an orientation to the virtual environment. This initial experience was especially beneficial for students with no prior exposure to VR technology. After completing various activities in the orientation application, students proceeded to a dedicated VR program focused on environmentally harmful waste. Participants completed a questionnaire before their exposure to the VR experience (see Table 2) and another immediately after the session (see Table 3). These questionnaires were designed to address the research questions and assess both the participants' initial level of understanding and how it evolved following their engagement with VR. The post-session questionnaire included questions about how well they understood the material, their enjoyment of the experience, and the ease of using VR technology. Data from the pre-questionnaire was analyzed statistically, with responses before and after the VR experience compared to evaluate any significant changes. This comparison allowed the study to assess how students' understanding and engagement evolved through their use of VR.

Table 2. Pre-Questionnaire results

INDICATOR	MEAN	DEVIATION	
Level of Digital Knowledge			
Comfort in using various digital devices	3.33	0.80	
Proficient in using software to create and present digital content	2.76	0.70	
Proficient in internet searching skills to find relevant information	3.57	0.51	
Familiarity with online learning platforms and digital tools	2.95	0.59	
How do students perceive VR technology			
Innovative and interesting	2.76	0.62	
Enhance learning experiences	3.05	0.38	
Easy to use	2.71	0.56	
Cost-effective	2.81	0.68	
Safe in terms of security and protection	2.76	0.77	

Table 3. Post-Questionnaire results

INDICATOR	MEAN	DEVIATION
What impact does VR technology have on students' educational experiences		
Captivating	3.76	0.54
Interactive	3.71	0.56
Realistic	3.33	0.80
Helpful	3.35	0.81
Effective	3.52	0.81
What contribution do VR applications make to students' engagement in the learning process?		
Captivating	3.71	0.64
Interactive	3.48	0.87
Enhances understanding	3.38	0.80
Stimulates creativity	3.67	0.48
Provides motivation	3.48	0.75
How do students perceive VR technology in an educational context		
Innovative and interesting	3.29	0.56
Enhance learning experiences	3.43	0.60
Easy to use	2.95	0.80
Cost-effective	2.48	0.87
Safe in terms of security and protection	2.95	0.67
What are the effects of using VR technology on the understanding of educational content?		
Improved understanding of educational content	3.00	0.77
Made educational content more engaging and captivating	3.39	0.98
Helped in retaining educational content better	3.50	0.51

By comparing pre- and post-questionnaire data (see Table 4), we were able to assess the effectiveness of the VR experience in enhancing students' educational outcomes. The post results highlighted the positive impact of VR technology on students' educational experiences. This knowledge can be used to enhance teaching methods, provide personalized educational resources, and optimize the integration of VR into the curriculum, effectively meeting student needs and improving learning experiences.

Table 4. Difference between pre- and post-experiment

Question	Indicator	Pre	Post
How do students perceive VR technology in an educational context	Innovative and interesting	2.76	3.29
	Enhances learning experiences	3.05	3.43
	Easy to use	2.71	2.95
	Cost-effective	2.81	2.48
	Safe in terms of security and protection	2.76	2.95

To maximize the benefits of VR in education, it is essential to address concerns related to usability, cost, and safety. Additionally, ongoing research and innovation are needed to fully explore VR's potential and tackle any remaining challenges.

Observation 1: VR technology significantly enhanced students' educational experiences, with many finding the content more captivating and interactive. The immersive nature of VR effectively captured students' attention, making the learning experience more dynamic and enjoyable.

Observation 2: VR applications greatly improved student engagement, especially in subjects that encourage creativity and innovation. The technology promotes an innovative approach, resulting in higher levels of engagement with the material.

Observation 3: While VR generally enhanced comprehension of instructional material, the impact varied among students. Some found the immersive experience particularly helpful for understanding complex concepts, while others experienced a less pronounced effect.

Observation 4: Student feedback on the value of VR in education was predominantly positive. However, challenges related to ease of use and cost-effectiveness were noted as potential barriers to wider acceptance and integration.

The Spearman correlation analysis revealed several statistically significant relationships between students' digital knowledge and their perceptions of VR in an educational context. Table 5 highlights these correlations.

Table 5. Spearman's correlation test of students' digital knowledge and their perceptions of VR in education

	Innovative	Enhances Learning	Easy to Use	Cost Effective	Safe for Use
Comfort with Digital Devices	-.20	.13	-.13	-.39	.00
Proficient in Software Use	.09	.38	.13	.25	.22
Internet Search Skills	.04	.06	.36	.80	.61
Familiarity with Online Platforms	.21	.47	.26	-.09	-.10

We found a moderate (.4 - .6) but statistically significant ($p < .001$) correlation between students' familiarity with online platforms and their perceptions of VR's educational benefits. Students who were more familiar with online learning platforms were more likely to see VR as improving their learning experiences ($r = .47$). This suggests that students who have already used digital learning tools might view VR as a valuable extension of their current learning methods.

We also found a strong (.6 - .8) correlation between internet search skills and students' perceptions of VR's cost-effectiveness ($r = .80$) and safety ($r = .61$). Students with strong internet search skills were more likely to see VR as a cost-effective tool that offers safe and secure experiences. This may indicate that students with strong digital navigation skills have a greater appreciation for the value and security benefits of VR technology.

On the other hand, a slight (-.2 to -.39) negative correlation was found between comfort with digital devices and the perception of VR as cost-effective ($r = -.39$). Students who were already comfortable with digital devices tended to see VR as less cost-effective, perhaps because they already had access to other digital tools that effectively met their needs.

Finally, there was a weak (.1 - .39) positive correlation between software proficiency and the belief that VR enhances learning (r = .38). Students proficient in software tools were slightly more likely to view VR as an enhancement to learning, suggesting that their comfort with software applications might make them more receptive to VR's interactive potential in education.

To summarize, these correlations indicate that various digital competencies, such as familiarity with online platforms and internet search skills, positively impact students' perceptions of VR's educational potential, cost-effectiveness, and safety. However, familiarity with existing digital devices may lead to a more critical assessment of VR's cost-effectiveness, possibly due to comparisons with other familiar technologies.

We may have several significant findings from the student feedback gathered after their VR technology experience, specifically addressing, "How can learning sessions with VR technology be optimized in the context of education?". According to the feedback provided by students, VR technology has the potential to enhance learning outcomes by offering an engaging, participatory, and joyful experience that improves comprehension and retention of course material. To fully capitalize on this technology in education, continued research and development are essential to further explore its potential and address existing challenges.

Integrating VR technology into educational environments presents unique opportunities as well as challenges that might impact the user's experience. The success of VR in education depends on several factors, despite its potential to enhance learning through immersive and interactive settings. A key challenge is students' familiarity with the technology. Limited technological competence can complicate VR use, causing frustration and adding learning complexity. Additionally, performance issues, such as delays in broadcasting, can disrupt the immersive experience, diminishing students' enjoyment and level of engagement. Despite these challenges, overall student feedback regarding the use of VR in education has been positive, with most participants reporting few negative experiences. This suggests that although technological and skill-related challenges exist, they do not significantly affect the overall effectiveness and appeal of VR as an educational tool.

5. Discussions

This study explored the incorporation of VR technology to enhance educational outcomes by aligning global learning objectives with students' personal values. The findings suggest that students generally view VR technology in education favorably, as it effectively captures their attention, enhances their learning experiences, and improves their understanding and retention of educational content. However, to fully capitalize on VR's benefits in education, it is essential to address issues such as user-friendliness, cost-effectiveness, and safety. Prioritizing safety and security in VR experiences is crucial for fostering students' trust and confidence in the technology.

Several conclusions can be drawn from the data on students' perceptions and experiences with VR technology in education:

RQ1. What impact does VR technology have on students' educational experiences?

VR technology significantly enhances students' educational experiences, with students rating it as highly captivating (mean score: 3.76, standard deviation: 0.54) and interactive (mean score: 3.71, standard deviation: 0.56). Students also perceive the technology as moderately realistic (mean score: 3.33, standard deviation: 0.80) and helpful (mean score: 3.35, standard deviation: 0.81). While VR is generally considered an effective learning tool (mean score: 3.52, standard deviation: 0.81), its perceived effectiveness varies among students.

RQ2. What contribution do VR applications make to students' engagement in the learning process?

VR applications significantly enhance students' engagement, making learning more captivating (mean score: 3.71, standard deviation: 0.64) and interactive (mean score: 3.48, standard deviation: 0.87). Students noted that VR applications improve content understanding (mean score:

3.38, standard deviation: 0.80) and stimulate creativity (mean score: 3.67, standard deviation: 0.48). Additionally, VR provides motivation (mean score: 3.48, standard deviation: 0.75), although the level of motivation experienced varies among students.

RQ3. How do students perceive VR technology in an educational context?

Students generally perceive VR technology as innovative and interesting (mean score: 3.29, standard deviation: 0.56). They also believe that it enhances learning experiences (mean score: 3.43, standard deviation: 0.60). However, factors such as ease of use (mean score: 2.95, standard deviation: 0.80), cost-effectiveness (mean score: 2.48, standard deviation: 0.87), and safety (mean score: 2.95, standard deviation: 0.67) can influence their overall perception. While VR is appreciated for its potential to innovate, these factors may hinder its broader acceptance and integration into educational settings.

RQ4. What are the effects of using VR technology on the understanding of educational content?

VR positively impacts students' understanding and retention of educational content. Students reported that VR helps them better understand the material (mean score: 3.00, standard deviation: 0.77) and makes the content more engaging and captivating (mean score: 3.39, standard deviation: 0.98). Furthermore, VR aids in better retention of educational content (mean score: 3.50, standard deviation: 0.51), indicating that the immersive nature of VR can enhance both comprehension and memory retention. However, the impact of VR varies, with different students experiencing different levels of benefit.

RQ5. How can learning sessions with VR technology be optimized in the context of education? - This question looks for ways to improve learning sessions while taking into account the input and outcomes from the study's use of VR technology.

The feedback from students suggests that VR technology successfully creates captivating and interactive learning experiences. Many students appreciated the interaction with VR, finding it an engaging way to learn new concepts. However, technical issues such as transmission lag and slow movement slightly detracted from the user's experience. Students also expressed interest in more varied content and additional interactive options, highlighting a need for diversification in VR applications. Overall, the findings emphasize VR's potential to enhance education, although there are still areas for improvement. As VR technology continues to advance, further research and development will be essential to maximize its benefits and support its effective integration into educational settings. While certain aspects of VR could be refined, its educational potential is clear, and ongoing advancements will be crucial for expanding its implementation in learning environments.

The study's findings indicate that students' digital competencies influence their perceptions of VR technology in education. Familiarity with online platforms showed a moderate positive correlation with viewing VR as beneficial to learning, suggesting that students accustomed to digital learning tools may see VR as a natural extension that enhances their academic experience. Encouraging students to engage with online platforms could therefore facilitate VR acceptance by making it feel like a familiar tool.

A strong correlation was found between students' internet search skills and their perceptions of VR as both cost-effective and secure. Students with strong online research abilities appear more likely to recognize the value and safety of VR, possibly because these skills enable them to appreciate its practical benefits. This implies that fostering digital literacy, particularly in online research and information evaluation, could lead to a more favorable perception of VR's advantages. Conversely, students already comfortable with various digital devices tended to be more critical of VR's cost-effectiveness, possibly because they feel well-equipped with existing technology. For these students, VR may seem redundant rather than uniquely valuable. To gain acceptance from tech-savvy students, it may be beneficial to emphasize the unique experiences and advantages VR offers beyond conventional digital tools.

Additionally, students proficient in software showed a slight tendency to view VR as an enhancement to learning, suggesting that basic software skills can ease the transition to VR. Familiarity with digital interfaces may make students more receptive to VR's interactive features.

These findings indicate that different digital skills uniquely influence students' openness to VR. Educators can promote VR acceptance by fostering digital literacy, particularly in online navigation and familiarity with digital learning tools. Highlighting VR's distinct features may be especially important for students already comfortable with other digital technologies, helping them recognize VR's value in education.

To optimize VR's effectiveness in education, ongoing research and development are essential for addressing existing challenges and refining applications. By focusing on relevant learning events and eliminating extraneous content, VR can better support students' academic achievement and personal success. Incorporating time management techniques and personalized feedback can further enhance the experience, promoting accountability, flexibility, and well-being.

As education evolves with advanced technologies, future work on VR should aim to further enrich and diversify the learning experience. A promising direction involves integrating AI within VR to provide personalized guidance and real-time feedback, tailoring learning experiences to individual student needs and learning styles. This aligns with the goals of Education 4.0, which emphasizes student-centered, adaptive learning environments that use digital tools to foster autonomy and personalized education. Expanding VR content to cover a wider range of subjects and educational scenarios will make VR more inclusive, accommodating diverse learner needs.

6. Conclusions and future work

This study demonstrates that VR significantly enhances engagement and learning outcomes in pre-university education. By immersing students in dynamic and interactive environments, VR facilitates deeper understanding and retention of educational content. Positive feedback from students underscores VR's value as an engaging and effective educational tool. However, the study also identified challenges, including technical issues, limited content diversity, and concerns about accessibility and cost. Addressing these challenges is essential to fully realizing VR's long-term educational benefits.

The Spearman correlation analysis in this study reveals how various digital competencies influence students' perceptions of VR technology in education. Key findings indicate that familiarity with online platforms moderately correlates with students viewing VR as beneficial to their learning, suggesting that prior exposure to digital tools can make VR feel like a natural extension of the academic experience. Similarly, a strong correlation between internet search skills and perceptions of VR as both cost-effective and secure indicates that students with well-developed online research abilities are more likely to appreciate VR's practical benefits, possibly because these skills help them recognize VR's value in an educational context.

Despite limitations, such as a small sample size and short-term focus, the results suggest that VR can play a transformative role in education. To validate these findings, future research should involve larger, more diverse groups and incorporate longitudinal studies to assess VR's long-term impact on performance and retention. Future research should focus on enhancing VR's capabilities, expanding its applications, and diversifying content to cover a broader range of subjects and educational scenarios.

Hand tracking technology also offers exciting possibilities for improving VR's interactivity and immersion. By enabling students to interact more naturally with virtual environments, hand tracking bridges theoretical knowledge and practical application, supporting experiential learning approaches central to Education 4.0. This can cultivate critical thinking, problem-solving skills, and creativity.

In conclusion, the future of VR in education depends on continuous advancements in users' experience through AI-driven personalization, expanded content diversity, and advanced interaction methods like hand tracking. These developments will align with Education 4.0 goals, positioning VR as a key tool in the future of education.

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