2025, VOL 15, NO 2, 1212-1229
DOI: 10.48146/odusobiad.1544365
Received Date: 05.09.2024
Acceptence Date: 30.10.2024

Research Article

Open Access

Sustainable educational virtual reality environments: Development, integration, and pedagogical alignment[1,2]

Ali Geriş[3], Barış Çukurbaşı[4], Yeliz Tunga[3], Gizem Engin[5]

[3]Manisa Celal Bayar University, Faculty of Education, Manisa, Türkiye; [4]Manisa Celal Bayar University, Technical Sciences Vocational School, Manisa, Türkiye; [5]Ege University, Faculty of Education, İzmir, Türkiye.

ABSTRACT

This study comprehensively addresses the sustainable integration of Virtual Reality (VR) technologies in education, as well as the development and enhancement process of the Educational Virtual Reality Campus (EVRECA) platform. The research first examines the potential benefits and technical challenges associated with the use of VR technologies in educational environments, focusing on how these technologies can be effectively integrated into educational processes. The EVRECA platform was developed based on a solid technical infrastructure and principles of sustainability, designed to support diverse educational content. In particular, the study delves into the development process of interactive VR modules that enable students to explore complex concepts in immersive virtual environments. During this process, extensive pilot testing was conducted to optimize the user experience, and improvements were made based on user feedback. The study also discusses the access challenges encountered during the broader implementation of VR technologies in education and offers solutions to these issues. Scalable solutions were developed to ensure the EVRECA platform's accessibility to a wider audience, and the findings from this effort provide valuable insights for future educational technology projects. Ultimately, the study presents recommendations for the widespread adoption and effective integration of sustainable VR applications in educational technologies.

KEYWORDS

Virtual reality, educational technology, sustainable educational platforms, immersive learning.

Sürdürülebilir eğitsel sanal gerçeklik ortamları: Geliştirme, entegrasyon ve pedagojik uyum

ÖZET

Bu çalışma, sanal gerçeklik (VR) teknolojilerinin eğitimde sürdürülebilir entegrasyonunu ve Eğitsel Sanal Gerçeklik Kampüsü (EVRECA) platformunun geliştirilme ve iyileştirilme sürecini kapsamlı bir şekilde ele almaktadır. Araştırmada, ilk olarak VR teknolojilerinin eğitim ortamlarında kullanımının potansiyel faydaları ve teknik zorlukları incelenmiş, ilgili teknolojilerin eğitim süreçlerine nasıl entegre edilebileceği üzerinde durulmuştur. EVRECA platformu, sağlam bir teknik altyapı ve sürdürülebilirlik ilkelerine dayalı bir yapı oluşturularak geliştirilmiş, farklı eğitim içeriklerini destekleyecek şekilde tasarlanmıştır. Özellikle, karmaşık kavramların sanal ortamlarda etkileşimli olarak keşfedilmesine olanak tanıyan VR modüllerinin geliştirilmesi süreci ayrıntılı olarak ele alınmıştır. Bu süreçte, platformun kullanıcı deneyimini optimize etmek amacıyla kapsamlı pilot uygulamalar yapılmış ve kullanıcı geri bildirimlerine dayalı iyileştirmeler gerçekleştirilmiştir. Çalışma ayrıca, VR teknolojilerinin eğitimde yaygınlaştırılması sırasında karşılaşılan erişim zorlukları ve bu sorunlara yönelik çözüm önerilerini tartışmaktadır. EVRECA platformunun geniş kitlelere hitap edebilmesi için geliştirilen ölçeklenebilir çözümler ve bu çözümler ışığında elde edilen bulgular, gelecekteki eğitim teknolojileri projelerine önemli katkılar sunmaktadır. Sonuç olarak,

[1] This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 122K775. The authors thank to TUBITAK for their supports.

[2] A part of this study was presented as an oral presentation at the 8th International Academic Conference on Teaching, Learning, and Education, held on 28–30 November 2024 in Vienna, Austria.

Sorumlu Yazar: ali.geris@cbu.edu.tr

çalışma, eğitim teknolojilerinde sürdürülebilir VR uygulamalarının yaygınlaştırılması ve etkin entegrasyonuna yönelik öneriler geliştirmektedir.

ANAHTAR KELİMELER

Sanal gerçeklik, eğitsel teknoloji, sürdürülebilir eğitsel platformlar, çevreleyen öğrenme.

Introduction

In recent years, the field of educational technology has witnessed a rapid and significant expansion in the use of Virtual Reality (VR), a technology that is increasingly recognized for its transformative potential in reshaping the learning experience. VR technologies create immersive and interactive environments, offering students an engaging and multisensory platform that has the potential to significantly enhance the quality of education. The integration of VR into educational settings has been shown to not only increase student engagement and retention of knowledge but also to foster the development of practical skills by allowing learners to explore complex concepts within a controlled, virtual environment. These benefits have been particularly evident in fields requiring hands-on learning, such as engineering, medicine, and architecture, where VR's ability to simulate real-world scenarios provides invaluable experiential learning opportunities (Fei et al., 2023; Yu & Xu, 2022).

Emerging research underscores VR's substantial impact on student engagement and learning outcomes, showing that VR environments can significantly increase student engagement levels— sometimes by as much as 180% compared to traditional methods— and enhance comprehension and learning results (Grewe & Gie, 2023). In addition, VR’s capability to provide immersive, hands-on experiences has proven beneficial in fields like STEM education, where student motivation and understanding of complex concepts are crucial (Chen et al., 2024; Rafiq et al., 2022). Such studies highlight the effectiveness of VR in fostering a deeper engagement with educational content, making it an increasingly valuable tool for experiential learning. Moreover, the application of VR extends beyond traditional educational contexts, finding utility in educational games, art, and even political education, thus demonstrating its versatility and broad applicability across diverse learning environments (Lin et al., 2023; Vemula, 2021).

However, the promising advantages of VR in education are accompanied by significant challenges that complicate its integration into educational environments. One of the primary obstacles is the technical complexity associated with developing and maintaining VR platforms. This complexity manifests in various forms, including the high cost of VR hardware, the specialized technical expertise required to create and manage VR content, and the difficulties in achieving seamless integration across different devices and platforms (Bheda et al., 2021). Furthermore, the immersive nature of VR experiences demands low-latency and high-bandwidth connections, which adds another layer of complexity to the implementation process, particularly in educational settings that may lack the necessary technological infrastructure (Geris et al., 2024). Addressing these technical challenges is crucial for the effective adoption and scalability of VR in education, ensuring that these technologies can be widely implemented and sustained over time.

Beyond the technical hurdles, the widespread adoption of VR in education is further impeded by issues related to educational content and instructional practices. The lack of standardized educational content, coupled with insufficient teacher training and the limited availability of resources tailored to diverse learning needs, hinders the broader application of VR technologies in educational contexts. Existing solutions often fall short of addressing these issues, resulting in a gap between the potential and the actual impact of VR technologies in education. For example, the absence of comprehensive platforms that enable educators to easily create, customize, and deploy VR content across various curricula presents a significant barrier to the widespread use of VR in classrooms (Gao, 2023; Yan et al., 2021). Additionally, the challenges associated with scaling VR solutions across different educational institutions further complicate efforts to make these technologies more accessible and effective in diverse educational settings (Cai et al., 2023).

Another critical area that has received insufficient attention in the existing literature is the sustainability of VR platforms in educational settings. While VR technologies hold enormouspromise for enhancing educational outcomes, their long-term sustainability—both in terms of technological upkeep and educational relevance—remains underexplored. Sustainable VR platforms require continuous updates, regular maintenance, and ongoing pedagogical alignment to remain effective over time (Horváth, 2021; Sanfilippo et al., 2022). Without a sustainable framework, the long-term viability of VR in education is at risk, as platforms may quickly become outdated or fail to meet evolving educational needs. Thus, addressing the research gap in the sustainability of educational VR platforms is essential for ensuring that these technologies continue to provide value and remain integral to educational innovation.

The EVRECA platform, developed as part of this study, seeks to address these challenges by offering a robust, sustainable framework for the integration of VR technologies in education. EVRECA is designed not only to enhance the technical aspects of VR platforms but also to incorporate comprehensive educational content that can be easily adapted and customized to meet the diverse needs of learners and educators. By focusing on sustainability and scalability, EVRECA aims to bridge the gap between the potential and practical application of VR in education, facilitating the broader adoption of these technologies in a way that is both impactful and sustainable. The platform's emphasis on user-friendly interfaces and adaptive learning environments is specifically tailored to overcome the barriers that have traditionally hindered the effective integration of VR in education.

This study aims to examine the technical and educational foundations of the EVRECA platform, with a particular emphasis on its sustainability and integration processes. The paper is structured to first discuss the development and technical details of the EVRECA platform, followed by an exploration of its educational applications and potential impacts. The final sections provide an analysis of the challenges encountered during the development and implementation phases, along with recommendations for future research and development in the field of educational VR technologies. Through this examination, the study seeks to contribute to the ongoing discourse on the sustainable integration of VR in education, offering insights that are both technically sound and pedagogically relevant.

Background of the study

Integration of educational virtual reality technologies

Virtual Reality (VR) technology has rapidly become a cornerstone of innovation in education, offering unprecedented opportunities for immersive and interactive learning experiences. By creating simulated environments that replicate real-world scenarios, VR allows students to engage deeply with complex concepts that would otherwise be abstract or difficult to visualize. For instance, in fields like biology or engineering, VR can simulate molecular structures or mechanical systems, providing students with hands-on experience that enhances their understanding and retention of knowledge (Cai et al., 2023; Purnama & Pranoto, 2023). Furthermore, VR technology supports the development of critical thinking and problem-solving skills by allowing students to explore different outcomes and scenarios within a safe, controlled environment (Liao, 2023). The educational potential of VR is thus vast, but realizing this potential requires careful consideration of both the pedagogical frameworks and the technological capabilities that underpin these tools (Shaukat, 2023).

However, the integration of VR into educational settings is not without its challenges, and these challenges are well-documented in the literature. One of the primary issues is the high cost of

VR hardware and software, which can be prohibitive for many educational institutions, particularly in underfunded or rural areas (Geriş, 2023). Additionally, the lack of standardized content and best practices for VR in education means that educators often face significant difficulties in selecting and implementing VR tools that are both effective and aligned with curriculum goals (Gao, 2023). Technical issues such as the need for high-performance computing resources and reliable internet connectivity further complicate the deployment of VR in classrooms, making it challenging to scale these technologies across different educational environments (Pirker & Dengel, 2021). These barriers highlight the need for continued research and investment in the development of cost-effective, scalable VR solutions that can be widely adopted in diverse educational settings.

The technical infrastructure supporting VR platforms is crucial for their successful integration into educational systems. A robust infrastructure includes not only the hardware, such as high-resolution displays and responsive input devices, but also the software that powers VR environments. The development of middleware that facilitates seamless data exchange between VR applications and other educational software is essential for creating integrated learning experiences (Wang et al., 2022). Moreover, the interoperability of VR platforms is a critical factor, as educational institutions often use a variety of technological tools that need to function together smoothly. Ensuring that VR content can be accessed across different devices and platforms requires a high level of standardization and flexibility in the design of VR systems (Li et al., 2023). Addressing these technical challenges is vital for the widespread adoption of VR technologies in education, enabling a more cohesive and effective learning environment.

To fully leverage the potential of VR in education, it is imperative that both the development of VR technologies and the technical infrastructure that supports them are approached with a comprehensive strategy. This strategy must include the development of pedagogically sound VR content, the establishment of scalable and sustainable technical frameworks, and the creation of accessible and affordable VR solutions for all educational institutions. By addressing these interconnected challenges, VR can truly become a transformative force in education, enhancing learning outcomes and expanding access to high-quality educational experiences across the globe.

Sustainable educational VR platforms

Sustainability has become an essential consideration in the development of educational technologies, reflecting a broader societal shift towards practices that support long-term environmental, social, and economic well-being. In the context of educational technologies, sustainability encompasses not only the creation of learning tools that are durable and adaptable but also those that foster ongoing learning and development aligned with sustainable principles (Abad-Segura et al., 2020). Educational platforms that incorporate sustainability principles tend to focus on reducing the environmental impact of their operations, such as minimizing energy consumption and waste, while also ensuring that their content promotes sustainability literacy among learners (Hsiao & Su, 2021). Virtual Reality (VR) technologies hold significant potential for promoting sustainable education by providing immersive learning experiences that can convey complex sustainability concepts in an engaging and memorable way (Ebinger et al., 2022).

Despite the potential benefits, the development of sustainable educational VR platforms is fraught with challenges. One of the primary issues is the high resource demand of VR technologies, which often require substantial computational power and energy consumption, posing a contradiction to sustainability goals (Li et al., 2023). Additionally, the rapid pace of technological advancement can render VR hardware and software obsolete quickly, leading to issues of electronic waste and the need for constant updates and replacements (Ronaghi, 2023). There are also challenges related to ensuring accessibility and inclusivity in VR education, as the cost and technical complexity of VR systems can limit their use to well-resourced institutions, thus exacerbating educational inequalities (Mentsiev et al., 2023). To mitigate these inequalities and promote access across a wider range of educational settings, strategies such as mobile-compatible VR applications and cloud-based VR experiences are effective, allowing institutions with limited resources to adopt immersive learning tools without extensive hardware investments (Kee & Zhang, 2022; Park & Kim, 2022). Addressing these challenges is crucial for the development of truly sustainable VR educational platforms that can be widely adopted and maintained over time.

To overcome these challenges, the development of sustainable VR platforms must be guided by principles that prioritize long-term usability, minimal environmental impact, and adaptability to future technological changes. This involves designing VR systems that are energy-efficient and capable of being upgraded without requiring complete replacement, thereby reducing electronic waste (Kee & Zhang, 2022). Additionally, sustainable VR platforms should be developed with a focus on scalability and accessibility, ensuring that they can be used across different educational settings and by diverse populations (Park & Kim, 2022). Incorporating features such as modular design and cloud-based updates can further enhance the sustainability of these platforms by allowing them to evolve alongside technological advancements without necessitating significant resource expenditure (Lee & Hwang, 2022).

As VR continues to be integrated into educational systems, it is critical that sustainability remains at the forefront of its development. By focusing on creating VR platforms that are not only technologically advanced but also environmentally and socially responsible, educators and developers can ensure that these tools contribute positively to both education and broader sustainability goals. This holistic approach will help in building resilient educational technologies that support lifelong learning and the sustainable development of future generations.

Contributions of educational VR platforms to learning environments

Interactive learning environments have become increasingly important in modern education, as they foster engagement, critical thinking, and active participation among students. Virtual Reality (VR) platforms excel in creating these immersive environments by allowing learners to interact with content in a three-dimensional space. This interaction not only enhances the retention of information but also supports the development of practical skills by simulating real-world scenarios (Azis & Cantafio, 2023). The ability of VR to create highly engaging and contextualized learning experiences makes it a powerful tool in educational settings, particularly in disciplines that require hands-on learning, such as engineering, medicine, and architecture (Mouttalib et al., 2023). Moreover, VR platforms offer students the opportunity to explore and experiment within a safe environment, thereby reducing the risk associated with learning complex or hazardous tasks (Niu et al., 2021).

Educational VR platforms contribute significantly to pedagogy by offering unique opportunities for experiential learning, which is crucial for deep understanding and skill acquisition. These platforms are particularly effective in supporting the dual coding theory, where the combination of visual and verbal information enhances learning outcomes (Petersen et al., 2021). The immersive nature of VR allows for the creation of rich, multisensory learning experiences that engage multiple cognitive pathways, thereby improving memory retention and comprehension (Sanfilippo et al., 2022). Additionally, VR platforms facilitate personalized learning by allowing educators to tailor experiences to the individual needs and learning styles of students, which is particularly beneficial in diverse classroom settings (Horváth, 2021). This adaptability not only enhances student engagement but also helps to bridge gaps in traditional teaching methods, making education more inclusive and effective.

VR technology offers adaptable learning environments that can be tailored to different educational levels, enhancing learning experiences across age groups. At the elementary level, VR can support basic exploration and discovery learning through virtual nature tours or historical site visits, enabling young students to visually engage with otherwise abstract concepts (Lin et al., 2023). At the secondary level, more complex simulations in subjects like biology or chemistry allow for experiential learning, where students can perform virtual experiments that deepen their understanding of scientific processes (Gao, 2023). For university students, VR offers advanced applications such as virtual laboratories in fields like health sciences and engineering, providing hands-on practice within a controlled, immersive setting (Azis & Cantafio, 2023). These tailored applications highlight VR's potential as a transformative educational tool across diverse learning contexts, fostering engagement and skill development at every stage.

Beyond academic skills, VR environments foster essential social competencies by enabling collaborative learning experiences. Through group-oriented VR modules, students are encouraged to engage in teamwork, problem-solving, and interpersonal communication, which are vital for both academic and personal growth (Horváth, 2021; Petersen et al., 2021). For instance, VR simulations can facilitate team-based projects where students collaborate to complete tasks, enhancing their ability to communicate effectively and work together towards shared objectives. This interactive setting not only supports individual learning outcomes but also cultivates a sense of social responsibility and cooperation, reflecting VR's potential to strengthen social dynamics within educational environments (Romano et al., 2023).

The integration of VR into educational environments represents a significant shift in pedagogical approaches, offering a new paradigm for interactive and experiential learning. By leveraging the unique capabilities of VR, educators can create learning environments that are not only engaging and effective but also tailored to meet the diverse needs of students. The continued development and application of VR in education has the potential to contribute to advancements in teaching methodologies, which may enrich the educational experience and potentially improve learning outcomes across various disciplines. As we move forward, it is essential to continue exploring the full potential of VR in education, ensuring that these technologies are used to their maximum advantage in creating innovative, effective, and inclusive learning environments.

Methodology

The methodology employed in this project was designed to systematically guide the development, implementation, and evaluation of the VR educational platform. This section provides an overview of the methodological approach, outlining the key phases of the project and the strategies used to address the challenges encountered throughout the process. The project was structured in distinct phases, each building upon the before, ensuring a coherent and effective development pathway. These phases included initial planning and goal setting, design and preliminary preparations, technology selection and infrastructure development, content creation, integration, testing, and finally, dissemination.

Figure 1 Five steps to development and integration process

The following sections detail each phase of the project, highlighting the specific methods and approaches used to achieve the project's objectives. The overall process is summarized in

Figure 1, which provides a visual representation of the project's workflow, from conception to deployment. This figure encapsulates the sequential steps taken and the iterative cycles of development and feedback that were crucial to refining and finalizing the platform.

Development and integration process

Project planning and design

The planning and design phase of the EVRECA project played a pivotal role in shaping the platform's development, with a strong focus on meeting both technological and educational objectives. The process began with an in-depth needs assessment that identified significant gaps in existing educational technologies, particularly in the integration of VR into traditional learning environments. This assessment involved extensive consultations with educators, curriculum designers, and technology experts to ensure that the platform would address real-world educational challenges. These consultations provided critical insights into the specific needs of educators and students, which guided the goal-setting process and informed the development roadmap.

One of the key outcomes of this assessment was the identification of the need for a platform that could offer customizable VR experiences tailored to various educational contexts. To meet this need, the project team established clear, measurable objectives designed to guide the development process. These objectives included the creation of a modular architecture that would allow for the easy addition and modification of educational content, as well as the development of a user interface that could be intuitively navigated by users with varying levels of technical expertise. The planning stage also included the identification of potential risks, such as technological obsolescence and integration challenges, and the development of contingency plans to mitigate these risks.

The design phase was characterized by a user-centered approach, emphasizing the creation of an intuitive and engaging interface that would facilitate learning while being accessible to a wide range of users. The team employed principles of instructional design, focusing on creating a platform that could support diverse learning styles and provide immersive educational experiences. This involved the development of detailed prototypes and the execution of extensive usability testing. The prototypes were tested with a diverse group of educators and students, whose feedback was used to refine the user interface and ensure that it met the needs of all users. These tests highlighted the importance of accessibility features, such as adjustable text sizes and alternative input methods, which were subsequently integrated into the platform.

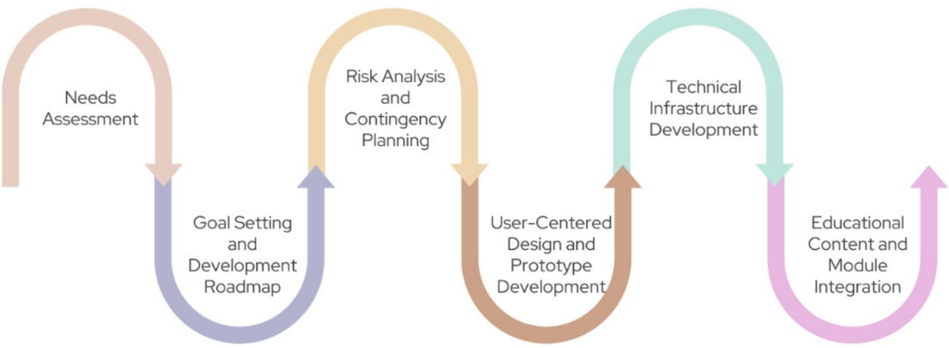

Figure 2 Project planning and design steps

In addition to the user interface, the design phase also included the development of the platform's technical infrastructure. A significant focus was placed on creating a robust and scalable database system that could support the storage and retrieval of large amounts of educational data. This database was designed to track user interactions, including session durations, task completion times, and learning outcomes, providing valuable data that could be used to personalize the learning experience. The infrastructure was also designed to support the integration of various VR hardware and software, ensuring compatibility with a wide range of devices. This included the transition from SteamVR to Unity's XR Interaction framework, which allowed the platform to support Oculus devices and provided a more seamless user experience.

Furthermore, the design phase involved close collaboration between the development team and educational experts to ensure that the platform's content was pedagogically sound and aligned with curriculum standards. The team worked to integrate VR modules that could be easily adapted to different educational settings, allowing educators to customize the content to meet their specific needs. This included the development of tools that allowed educators to create and modify VR content without needing extensive technical knowledge, thus democratizing the use of VR in education.

This comprehensive planning and design phase laid a solid foundation for the subsequent stages of the project. By aligning technical development with educational goals and ensuring that the platform was both user-friendly and scalable, the project team was able to create a robust framework that would support the successful implementation and long-term sustainability of the EVRECA platform. The careful consideration of user needs, combined with rigorous testing and iterative development, ensured that the platform was well-equipped to meet the challenges of modern education and provide meaningful learning experiences for all users.

Technology selection and infrastructure development

The technology selection and infrastructure development phase were critical to ensuring that the EVRECA platform could meet its ambitious goals of providing a scalable, reliable, and immersive educational experience. This phase involved a thorough evaluation of existing VR technologies and development environments, followed by the establishment of a robust infrastructure capable of supporting the platform's diverse functionalities.

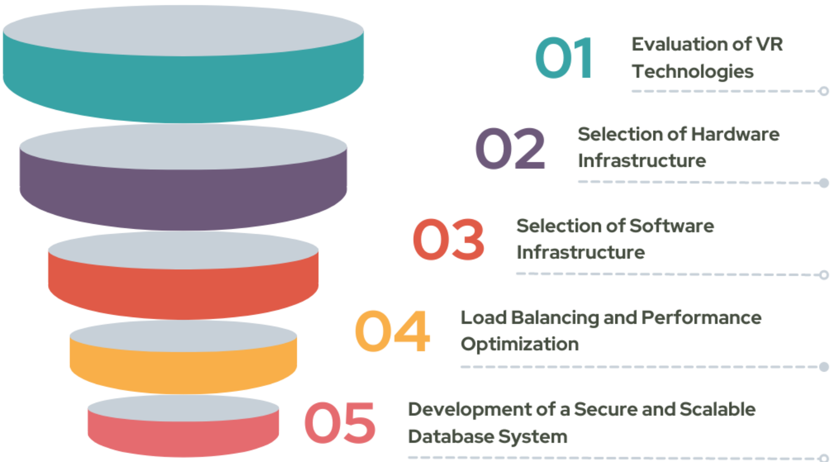

Figure 3 Layers of technology selection and infrastructure development

The project team began by assessing various VR development tools, focusing on those that could deliver high-quality 3D environments and seamless user interactions. After careful consideration, Unity was selected as the core development environment due to its versatility, extensive community support, and compatibility with a wide range of VR hardware, including Oculus and HTC Vive. Unity's XR Interaction Toolkit was particularly advantageous as it allowed for smooth transitions between different VR devices, which was essential for ensuring that the platform could be widely accessible across various educational institutions with differing technological resources. In addition to selecting the development environment, the team also focused on choosing the appropriate hardware and software infrastructure to support the platform's operations. This included the deployment of high-performance servers capable of handling the computational demands of real-time VR rendering and data processing. The infrastructure was designed with scalability in mind, incorporating cloud-based solutions to ensure that the platform could easily expand to accommodate increasing numbers of users and more complex educational content over time.

One of the key challenges during this phase was ensuring that the platform could maintain high levels of performance while supporting multiple concurrent users. To address this, the team implemented advanced load-balancing techniques and optimized the platform's server architecture to distribute the computational load efficiently. This approach not only improved the platform's performance but also enhanced its reliability, ensuring that users could access the platform without experiencing delays or interruptions, even during peak usage times. Furthermore, the infrastructure development process involved establishing a robust database system to manage and store the vast amounts of data generated by user interactions with the platform. This database was designed to support real-time data analytics, enabling the platform to track user progress, adapt content to individual learning needs, and provide educators with detailed insights into student performance. The database architecture was also optimized for security and data integrity, ensuring that all user data was protected and could be retrieved efficiently when needed.

Another significant aspect of this phase was the integration of cloud-based services to enhance the platform's accessibility and scalability. By leveraging cloud infrastructure, the platform could deliver VR experiences to users regardless of their geographic location or the capabilities of their local hardware. This was particularly important for educational institutions in under-resourced areas, where access to advanced technology may be limited. The use of cloud services also facilitated the regular updating and maintenance of the platform, allowing the development team to deploy new features and improvements quickly without requiring significant downtime. Throughout the technology selection and infrastructure development phase, the project team maintained a strong focus on flexibility and future-proofing the platform. The chosen technologies and infrastructure were selected not only for their current capabilities but also for their potential to adapt to future advancements in VR and educational technologies. This strategic approach ensured that the EVRECA platform would remain relevant and effective as educational needs and technological possibilities evolved.

Ensuring data security within the EVRECA platform has been a primary focus throughout its development. The platform implements robust encryption protocols to protect student data, alongside strict access controls to safeguard sensitive information against unauthorized access. Additionally, all user interactions are anonymized, with performance data securely stored and managed in compliance with educational data protection standards. These measures not only build trust among users but also align with broader ethical and legal standards in educational technology, ensuring a secure environment for immersive learning. The careful selection of technology and the meticulous development of a scalable, reliable infrastructure have been pivotal in establishing the EVRECA platform as a high-quality, accessible, and effective VR tool, capable of delivering immersive educational experiences to a diverse user base and advancing educational accessibility through innovation.

VR content development and integration

The development and integration of VR content were central to the success of the EVRECA platform, as the quality and effectiveness of the educational modules would directly impact the overall learning experience. This phase involved a comprehensive approach to content creation, focusing on both the pedagogical value of the VR experiences and their seamless integration into the existing platform infrastructure.

The content development process began with the identification of key educational objectives, which were informed by the needs assessment conducted during the project's initial stages. These objectives guided the creation of VR modules designed to address specific learning outcomes in various subject areas. The project team collaborated closely with subject matter experts and educators to ensure that the content was both accurate and relevant, aligning with curriculum standards and educational best practices. Using Unity as the development environment, the team created immersive 3D environments that allowed students to engage with complex concepts in a hands-on, experiential manner. The development process emphasized interactivity, with a focus on creating tasks and simulations that would actively involve students in the learning process. This included the development of interactive elements such as virtual labs, simulations of real-world scenarios, and problem-solving activities that required critical thinking and application of knowledge. These elements were designed to cater to different learning styles, providing both visual and kinesthetic learners with opportunities to engage with the material.

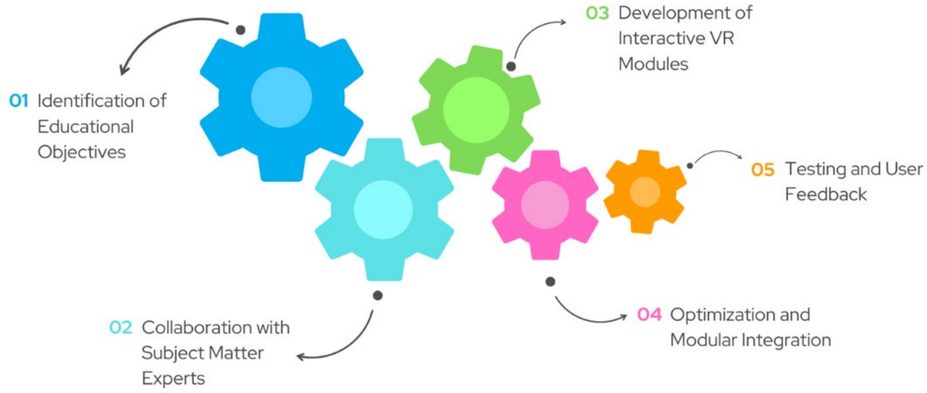

Figure 4 VR content development and integration steps

A significant challenge during this phase was ensuring that the VR content could be effectively integrated into the EVRECA platform without compromising performance or user experience. The integration process involved close collaboration between the content development team and the platform engineers to align the VR modules with the platform's existing architecture. This required the careful optimization of assets and code to ensure that the VR experiences could be delivered smoothly across different devices and network conditions. The team employed a modular approach to content integration, allowing for the easy addition and modification of VR modules as new content was developed or existing content was updated. Moreover, the project team worked to ensure that the VR content was accessible to a wide range of users, including those with varying levels of technological proficiency and access to different types of hardware. This involved the creation of adaptive content delivery mechanisms that could adjust the quality and complexity of the VR experiences based on the user's device capabilities and internet bandwidth. For example, the platform was designed to automatically scale the graphical fidelity of the VR content depending on the available resources, ensuring a consistent experience for all users regardless of their technical setup.

The integration phase also included extensive testing to ensure that the VR modules functioned correctly within the EVRECA platform and provided a seamless user experience. This testing involved both automated and manual methods, with a particular focus on identifying and resolving any performance issues that could impact the delivery of the VR content. User feedback gathered during pilot testing played a crucial role in this process, allowing the team to make necessary adjustments and optimizations before the full-scale deployment of the platform. Additionally, the team prioritized the integration of analytics tools within the VR modules to track student interactions and learning outcomes. These tools provided valuable data that could be used to refine the content and enhance its educational impact. The ability to monitor how students interacted with the VR modules, which tasks they found most challenging, and how their understanding evolved over time was instrumental in shaping ongoing content development efforts.

The successful development and integration of VR content into the EVRECA platform were the result of a carefully coordinated effort that balanced technical excellence with educational effectiveness. By focusing on creating high-quality, interactive learning experiences and ensuring their seamless integration into the platform, the project team was able to deliver a product that not only met its educational objectives but also set a new standard for the use of VR in education.

Pilot testing and user feedback

The pilot testing and user feedback phase was a critical part of the EVRECA project, offering essential insights into the functionality, usability, and educational effectiveness of the VR platform in real-world educational environments. This phase was carefully planned and executed to ensure that the VR modules were thoroughly tested under various conditions, providing the project team with valuable data for refining the platform before its full-scale deployment.

Pilot tests were conducted in educational settings that were specifically chosen for their readiness to integrate VR technology into the classroom. The testing focused on a particular grade level, with students participating in VR-based lessons that were aligned with their curriculum. Teachers facilitated the sessions, playing a crucial role in guiding students through the VR experiences and providing immediate feedback on the effectiveness of the modules. During the pilot testing, the project team monitored several key factors, including student engagement, ease of use, and the educational impact of the content. This hands-on approach allowed the team to observe how students interacted with the VR environment and identify any challenges they faced. The goal was to ensure that the VR modules were not only engaging but also pedagogically effective and accessible to all students, regardless of their prior experience with technology.

Figure 5 Pilot testing and user feedback steps

To evaluate the educational impact of the VR modules, the project team employed a combination of qualitative and quantitative methods. Pre- and post-assessment tests were used to measure students' knowledge acquisition and retention, providing a clear indication of the learning outcomes achieved through the VR lessons. These tests were crucial for understanding how well the VR content supported the educational objectives. Additionally, user observation and interaction tracking were utilized to gather data on how students navigated the VR environment and engaged with the content. Interaction tracking provided detailed insights into user behaviors, such as the time spent on tasks and the frequency of interactions, helping the team identify areas where improvements could be made. Feedback from educators was collected through structured focus groups and surveys. These feedback sessions were designed to gather in-depth evaluations of the VR content's alignment with educational standards, its integration into existing curricula, and its overall effectiveness in enhancing student learning. Teachers provided valuable insights into how the VR modules could be further refined to better meet the needs of both students and educators.

The feedback collected during the pilot phase was systematically analyzed to guide the ongoing development and optimization of the platform. Based on the feedback, the project team made targeted adjustments to the VR modules, such as improving navigation, enhancing interactive elements, and optimizing the user interface for greater intuitiveness. These refinements were essential for ensuring that the platform was both user-friendly and effective in delivering educational content. In addition to content improvements, technical evaluations were conducted to ensure that the platform performed reliably across different hardware configurations. Stress tests were carried out to simulate high-usage scenarios, and any technical issues identified during these tests were addressed through iterative development cycles. This approach ensured that the platform could handle the demands of real-world educational settings and provide a consistent user experience.

The pilot testing phase confirmed the EVRECA platform's effectiveness in educational settings, validating both its technical and pedagogical components. The insights gained from this phase were instrumental in refining the platform to better meet the needs of users, ensuring that it was ready for broader implementation. By incorporating direct feedback from both students and educators, the project team was able to create a VR platform that was well-aligned with educational objectives and capable of supporting a wide range of learning activities. The success of the pilot tests demonstrated that the platform could be effectively integrated into educational systems, paving the way for its deployment on a larger scale. The iterative process of testing, feedback collection, and refinement ensured that the final product was robust, user-centered, and ready to deliver meaningful educational experiences.

Dissemination and challenges

The dissemination of the EVRECA platform was a crucial phase that ensured the project's outcomes reached a broad audience, maximizing the impact of the developed VR educational technologies. This phase involved strategic planning and execution to effectively distribute the platform across various educational settings, while also addressing the technical, logistical, and pedagogical challenges that arose during the process. The dissemination strategy for the EVRECA platform was designed to ensure widespread adoption across different educational contexts, from primary and secondary schools to higher education institutions. The strategy involved multiple channels, including direct outreach to educational institutions, partnerships with educational technology providers, and presentations at academic conferences. By leveraging these channels, the project team aimed to introduce the platform to educators and administrators who could benefit from integrating VR into their teaching practices.

Figure 6 Dissemination and challenges steps

One of the key components of the dissemination strategy was the collaboration with educational authorities and institutions, which facilitated the platform's introduction into schools and universities. The project team provided detailed documentation, training materials, and technical support to ensure that educators could effectively implement the platform in their classrooms. Additionally, the platform was made available through popular educational technology platforms and VR content distribution channels, allowing for easy access and download by a wide range of users. To further enhance the platform's visibility and adoption, the team conducted webinars, workshops, and live demonstrations to showcase the capabilities of the EVRECA platform. These events were targeted at educators, curriculum developers, and educational policymakers, providing them with hands-on experience and demonstrating how the platform could be integrated into existing educational frameworks.

Despite the comprehensive dissemination plan, several challenges were encountered during this phase, particularly related to the variability in technological infrastructure across different educational institutions. One of the primary challenges was ensuring that the platform could be effectively used in schools with limited access to advanced VR hardware. To address this, the project team developed a scalable version of the platform that could run on less powerful hardware, ensuring that the educational content remained accessible to a broader audience. Another significant challenge was the varying levels of technological proficiency among educators. While some educators were highly experienced with digital tools, others required more extensive training to effectively use the VR platform. To overcome this, the team developed a series of professional development workshops and comprehensive training modules tailored to different levels of expertise. These resources were designed to build educators' confidence in using the platform and to provide them with practical strategies for integrating VR into their teaching.

The project also faced logistical challenges in distributing VR hardware to schools in remote or under-resourced areas. To mitigate these issues, partnerships were established with local educational authorities and technology vendors, who assisted in the distribution process and provided on-site technical support. Additionally, the team explored alternative distribution methods, such as cloud-based solutions, which allowed the platform to be accessed without the need for high-end VR equipment. Throughout the dissemination process, the project team gained valuable insights into the challenges of integrating cutting-edge technology into diverse educational environments. One of the key lessons learned was the importance of flexibility and adaptability in both the platform's design and the dissemination strategy. By creating a platform that could be easily scaled and adapted to different contexts, the team was able to overcome many of the obstacles that initially seemed insurmountable.

Moreover, the team recognized the critical role of ongoing support and training in ensuring the successful adoption of the platform. The feedback received from educators highlighted the need for continuous engagement and support, prompting the development of additional resources and follow-up training sessions to assist educators in their ongoing use of the platform. The dissemination phase of the EVRECA project successfully brought the VR educational platform to a wide audience, laying the groundwork for its long-term adoption and integration into educational systems. By addressing the challenges encountered during this phase with targeted solutions, the project team ensured that the platform could be effectively used in a variety of educational settings. The lessons learned during this process will inform future efforts to deploy innovative educational technologies, contributing to the ongoing evolution of digital learning environments.

Discussion and implications

The development and integration of VR technologies in educational settings have ushered in a new era of immersive learning experiences. The EVRECA project exemplifies the potential of VR to transform traditional educational methods by providing a scalable, interactive platform that enhances student engagement and learning outcomes. This discussion will evaluate the project's outcomes, drawing comparisons with existing literature, and explore the implications for future educational technology development.

The initial phase of the EVRECA project, focusing on project planning and design, laid a solid foundation for the subsequent development stages. The systematic approach ensured that the platform's architecture was both scalable and flexible, capable of supporting a wide range of educational modules. This strategic planning mirrors the findings of Hassan (2023), who emphasized the importance of aligning technological advancements with core educational values to ensure meaningful and equitable integration in educational contexts. Additionally, the iterative design process employed in EVRECA is consistent with best practices highlighted in the literature, which advocate for continuous refinement based on stakeholder feedback to enhance user engagement and learning outcomes (Montagud et al., 2022). The implications of this approach are significant, as it demonstrates that early and thorough planning is crucial for the successful deployment of educational technologies. By involving educators and students in the design process, the EVRECA project ensured that the platform met the actual needs of its users, thus enhancing its effectiveness and adoption potential.

The selection of robust technological frameworks and the development of a scalable infrastructure were critical to the success of the EVRECA platform. The use of Unity's XR Interaction Toolkit, for instance, provided the necessary flexibility to adapt the platform for use with various VR hardware, ensuring broad accessibility. This approach aligns with recent advancements in educational technology that emphasize the need for adaptive and scalable solutions capable of accommodating diverse user needs (Kalunga & Elshobosky, 2023; Wang, 2023). The EVRECA platform's focus on creating a resilient and scalable infrastructure has broader implications for the field of educational technology. It underscores the importance of selecting technologies that are not only cutting-edge but also capable of evolving with future technological advancements. This strategic foresight is essential for ensuring that educational platforms remain relevant and effective as the technological landscape continues to evolve.

The development and integration of VR content within the EVRECA platform were executed with a strong emphasis on educational effectiveness and user engagement. The creation of immersive, interactive environments allowed students to explore complex concepts in a hands-on manner, which is supported by the literature as an effective method for enhancing learning outcomes (Al-Gindy et al., 2020). Furthermore, the integration of machine learning algorithms to personalize and adapt content to individual student needs reflects current trends in educational technology, where AI is increasingly being used to tailor learning experiences (Wang, 2023). The successful integration of these technologies into the EVRECA platform highlights the potential for VR to not only engage students but also to deliver personalized educational experiences that cater to diverse learning styles. The implications of these developments are far-reaching, suggesting that VR platforms, when combined with AI-driven content adaptation, can significantly enhance the effectiveness of educational interventions.

Pilot testing played a crucial role in validating the EVRECA platform’s effectiveness in real-world educational settings. The insights gained from user feedback were instrumental in refining both the technical and educational components of the platform. This iterative approach is well-supported by the literature, which emphasizes the importance of user feedback in the continuous improvement of educational technologies (Romano et al., 2023). The EVRECA project’s methodology, which included both qualitative and quantitative assessments, ensured a comprehensive evaluation of the platform's impact on learning outcomes. The implications of these findings are twofold. First, they highlight the value of pilot testing in identifying and addressing potential issues before full-scale deployment. Second, they demonstrate the importance of incorporating user feedback into the development process to ensure that the final product is both effective and user-friendly.

The dissemination phase of the EVRECA project was met with several challenges, particularly in terms of ensuring equitable access to the platform across different educational settings. This challenge is echoed in the broader literature, which identifies accessibility and inclusivity as ongoing issues in the deployment of educational technologies (Iqbal et al., 2022). The EVRECA team’s efforts to develop a scalable version of the platform that could run on less powerful hardware addressed this issue, ensuring that the platform could be used in under-resourced areas. The broader implication of this experience is the critical need for educational technologies to be adaptable to various contexts and accessible to all users, regardless of their technological resources. This ensures that the benefits of such technologies are not limited to well-funded institutions but are available to a wider audience, thus promoting educational equity.

The findings of this study align with existing literature that underscores the potential of VR to enhance student engagement and learning outcomes, as demonstrated in fields like engineering and healthcare education (Rafiq et al., 2022; Singh et al., 2020). Unlike previous studies that focus predominantly on the technological aspects of VR, this research contributes by addressing the sustainability and scalability of VR platforms in diverse educational contexts. Furthermore, the EVRECA platform's emphasis on adaptability and ease of use positions it as a practical tool for institutions with limited resources, thereby extending VR's applicability beyond well-funded institutions (Han et al., 2023). This study's mixed-method approach also enriches theoretical understanding by providing user-centered insights into the platform's effectiveness, offering a holistic perspective that can inform future VR implementations in education.

The EVRECA project has demonstrated the transformative potential of VR in education, from planning and design to content development and dissemination. By aligning the platform with the latest technological advancements and educational needs, the project has set a benchmark for future educational technologies. The integration of user feedback, the focus on accessibility, and the use of AI for content personalization all point to a future where VR can play a central role in enhancing educational outcomes. Moving forward, it is crucial to continue refining these technologies, ensuring that they remain accessible, adaptable, and aligned with the evolving needs of educators and students alike.

Conclusion

The EVRECA project has effectively demonstrated the transformative capabilities of Virtual Reality (VR) in education, successfully developing a scalable, user-centered platform that significantly enhances student engagement and learning outcomes. The project's comprehensive methodology, which included meticulous planning, strategic technology selection, and iterative content development, ensured that the platform was both robust and adaptable to a wide range of educational contexts. By integrating AI-driven content personalization, the EVRECA platform has shown how emerging technologies can be harnessed to create immersive and tailored educational experiences, catering to diverse learning needs. The extensive pilot testing phase, supported by continuous feedback loops, was critical in refining the platform, addressing technical challenges, and ensuring its readiness for broader deployment.

Despite encountering challenges during the dissemination phase, particularly in ensuring that the platform was accessible across diverse educational environments, the project successfully navigated these obstacles by implementing scalable solutions and focusing on inclusivity. The EVRECA platform's ability to adapt to different technological infrastructures highlights its potential to reduce educational inequalities by making advanced learning tools available to a wider audience. As VR and AI technologies continue to evolve, the insights and methodologies developed through this project provide a valuable framework for future educational innovations, ensuring that they remain relevant, effective, and accessible to all learners, and thereby setting a new standard for the integration of immersive technologies in education.

Author contributions

Author 1: %40, Author 2: %30, Author 3: %20, Author 4: %10 contributed to the study.

Conflict of interest statement

There is no financial conflict of interest with any institution, organization, or person related to our article named "Development and integration process of a sustainable educational virtual reality campus."

References

Abad-Segura, E., Gonzalez-Zamar, M.-D., Rosa, A. L.-d. l., & Morales Cevallos, M. B. (2020). Sustainability of educational technologies: An approach to augmented reality research. *Sustainability*, *12*(10), Article 4091. https://doi.org/10.3390/su12104091

Al-Gindy, A., Felix, C., Ahmed, A., Matoug, A., & Alkhidir, M. (2020). Virtual reality: Development of an integrated learning environment for education. *International Journal of Information and Education Technology*, *10*(3), 171-175. https://doi.org/10.18178/ijiet.2020.10.3.1358

Azis, I. R., & Cantafio, G. (2023). The Role of Virtual Reality in Science and Technology Education. *Journal of Training, Education, Science and Technology*, *1*(2)13-18. https://doi.org/10.51629/jtest.v1i1.170

Bheda, R., Bhimani, D., Dharamshi, F., Sheth, S., Menon, R., Somra, R., Bhasuru, R., Mahajan, C., Gajbhiye, S., & Toradmalle, D. (2021). Educational Advancements in the Field of Augmented Reality and Virtual Reality. *2021 International Conference on Communication information and Computing Technology (ICCICT)*, Mumbai, India.

Cai, Y., Jin, Z., Liu, S., & Ying, J. (2023). Application and research of VR in education. *Applied and Computational Engineering*, *8*, 241-247. https://doi.org/10.54254/2755-2721/8/20230150

Chen, J., Fu, Z., Liu, H., & Wang, J. (2024). Effectiveness of virtual reality on learning engagement: A meta-analysis. *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT)*, *19*(1), 1-14. https://doi.org/10.4018/IJWLTT.334849

Ebinger, F., Buttke, L., & Kreimeier, J. (2022). Augmented and virtual reality technologies in education for sustainable development: An expert-based technology assessment. *TATuP-Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis/Journal for Technology Assessment in Theory and Practice*, *31*(1), 28-34. https://doi.org/10.14512/tatup.31.1.28

Fei, T., Mao, Q., Wu, F., & Yu, P. (2023). The Future Prospects of Importance of VR's Impact on Education. *Highlights in Science, Engineering and Technology*, *39*, 111-120. https://doi.org/10.54097/hset.v39i.6510

Gao, R. (2023). Virtual reality technology in the field of education. *Applied and Computational Engineering*, *16*, 228-233. https://doi.org/10.54254/2755-2721/16/20230897

Geris, A., Cukurbasi, B., Kilinc, M., & Teke, O. (2024). Balancing performance and comfort in virtual reality: A study of FPS, latency, and batch values. *Software: Practice and Experience* *54*(12), 2336-2348. https://doi.org/10.1002/spe.3356

Geriş, A. (2023). Bilgisayar Bilimi Eğitiminde Sanal Gerçeklik. In P. D. S. B. Kert (Ed.), *Teoriden Uygulamaya Bilgisayar Bilimi Eğitimi* (Vol. 1, pp. 159-182). Nobel Akademi Yayıncılık.

Grewe, M., & Gie, L. (2023). Can virtual reality have a positive influence on student engagement? *South African Journal of Higher Education*, *37*(5), 124-141. https://doi.org/10.20853/37-5-5815

Han, B., Weeks, D. J., & Leite, F. (2023). Virtual reality-facilitated engineering education: A case study on sustainable systems knowledge. *Computer Applications in Engineering Education*, *31*(5), 1174-1189. https://doi.org/10.1002/cae.22632

Hassan, G. (2023). Technology and the Transformation of Educational Practices: A Future Perspective. *International Journal of Economic, Business, Accounting, Agriculture Management and Sharia Administration (IJEBAS)*, *3*(1), 1596–1603. https://doi.org/10.54443/ijebas.v3i1.1136

Horváth, I. (2021). An analysis of personalized learning opportunities in 3D VR. *Frontiers in Computer Science*, *3*, Article 673826. https://doi.org/10.3389/fcomp.2021.673826

Hsiao, P.-W., & Su, C.-H. (2021). A study on the impact of STEAM education for sustainable development courses and its effects on student motivation and learning. *Sustainability*, *13*(7), Article 3772. https://doi.org/10.3390/su13073772

Iqbal, M. Z., Mangina, E., & Campbell, A. G. (2022). Current challenges and future research directions in augmented reality for education. *Multimodal Technologies and Interaction*, *6*(9), Article 75. https://doi.org/10.36227/techrxiv.16369224.v1

Kalunga, R., & Elshobosky, F. (2023). Using Immersive Technologies To Enhance Student Learning Outcomes In Clinical Sciences Education And Training. Education and New Developments, Porto, Portugal.

Kee, T., & Zhang, H. (2022). Digital experiential learning for sustainable horticulture and landscape management education. *Sustainability*, *14*(15), 9116. https://doi.org/10.3390/su14159116

Lee, H., & Hwang, Y. (2022). Technology-enhanced education through VR-making and metaverse-linking to foster teacher readiness and sustainable learning. *Sustainability*, *14*(8), 4786. https://doi.org/10.3390/su14084786

Li, F., Jiang, J., Qin, Q., Wang, X., Zeng, G., Gu, Y., & Guo, W. (2023). Application of sustainable development of teaching in engineering education: A case study of undergraduate course design of raman spectroscopy based on virtual reality (VR) technology. *Sustainability*, *15*(3), Article 1782. https://doi.org/10.3390/su15031782

Liao, X. (2023). Immersive Learning: Characteristics of Development of VR Education Technology and the Practice. *Adv. Educ. Technol. Psychol*, *7*, 107-111. https://doi.org/10.23977/aetp.2023.070119

Lin, Y., You, Y., & Zhou, Z. (2023). Application Of VR In the Field of Education. *Highlights in Science, Engineering and Technology*, *68*, 11-20. https://doi.org/10.54097/hset.v68i.11925

Mentsiev, A., Aygumov, T., & Zaripova, R. (2023). Harnessing virtual reality and simulation technologies in education for sustainable development. E3S Web of Conferences,

Montagud, M., Cernigliaro, G., Arevalillo-Herráez, M., García-Pineda, M., Segura-Garcia, J., & Fernández, S. (2022). Social VR and multi-party holographic communications: Opportunities, Challenges and Impact in the Education and Training Sectors. *arXiv preprint arXiv:2210.00330*. https://doi.org/10.48550/arXiv.2210.00330

Mouttalib, H., Tabaa, M., & Youssefi, M. (2023). Revolutionizing engineering education: Creating a web-based teaching platform for immersive learning experiences. *Journal of Smart Cities and Society*, *2*(3), 1-12. https://doi.org/10.3233/SCS-230012

Niu, M., Lo, C.-H., & Yu, Z. (2021). Embedding virtual reality technology in teaching 3D design for secondary education. *Frontiers in Virtual Reality*, *2*, Article 661920. https://doi.org/10.3389/frvir.2021.661920

Park, S., & Kim, S. (2022). Identifying world types to deliver gameful experiences for sustainable learning in the metaverse. *Sustainability*, *14*(3), Article 1361. https://doi.org/10.3390/su14031361

Petersen, G. B., Mottelson, A., & Makransky, G. (2021). Pedagogical agents in educational vr: An in the wild study. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan.

Pirker, J., & Dengel, A. (2021). The potential of 360 virtual reality videos and real VR for education—a literature review. *IEEE computer graphics and applications*, *41*(4), 76-89. https://doi.org/10.1109/MCG.2021.3067999

Purnama, I., & Pranoto, N. W. (2023). Virtual Reality for Future Education: Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 322-327. https://doi.org/10.29303/jppipa.v9i7.4485

Rafiq, A. A., Triyono, M. B., & Djatmiko, I. W. (2022). Enhancing student engagement in vocational education by using virtual reality. *Waikato Journal of Education*, *27*(3), 175-188. https://doi.org/10.15663/wje.v27i3.964

Romano, M., Frolli, A., Aloisio, A., Russello, C., Rega, A., Cerciello, F., & Bisogni, F. (2023). Exploring the potential of immersive virtual reality in Italian schools: a practical workshop with high school teachers. *Multimodal Technologies and Interaction*, *7*(12), Article 111. https://doi.org/10.3390/mti7120111

Ronaghi, M. H. (2023). The effect of virtual reality technology and education on sustainable behavior: A comparative quasi-experimental study. *Interactive technology and smart education*, *20*(4), 475-492. https://doi.org/10.1108/ITSE-02-2022-0025

Sanfilippo, F., Blazauskas, T., Salvietti, G., Ramos, I., Vert, S., Radianti, J., Majchrzak, T. A., & Oliveira, D. (2022). A perspective review on integrating VR/AR with haptics into stem education for multi-sensory learning. *Robotics*, *11*(2), Article 41. https://doi.org/10.3390/robotics11020041.

Shaukat, S. M. (2023). Exploring the potential of augmented reality (AR) and virtual reality (VR) in education. *International Journal of Advanced Research in Science, Communication and Technology*, *3*(2), 51-56. https://doi.org/10.48175/ijarsct-12108

Singh, A., Ferry, D., Ramakrishnan, A., & Balasubramanian, S. (2020). Using virtual reality in biomedical engineering education. *Journal of Biomechanical Engineering*, *142*(11), Article 111013. https://doi.org/10.1115/1.4048005

Vemula, S. (2021). Leveraging VR/AR/MR and AI as innovative educational practices for "iGeneration" students. In *Handbook of research on equity in computer science in P-16 education* (pp. 265-277). IGI Global. https://doi.org/10.4018/978-1-7998-4739-7.ch015

Wang, C., Tang, Y., Kassem, M. A., Li, H., & Hua, B. (2022). Application of VR technology in civil engineering education. *Computer Applications in Engineering Education*, *30*(2), 335-348. https://doi.org/10.1002/cae.22458

Wang, Y. (2023). Procedural content generation for VR educational applications: The investigation of AI-based approaches for improving learning experience. *Applied and Computational Engineering*, *17*, 23-21. https://doi.org/10.54254/2755-2721/17/20230905

Yan, R., Su, Y., Li, Q., & Wang, B. (2021). VR Technology Applied in The Teaching of Equipment Courses. 2021 2nd International Conference on Information Science and Education (ICISE-IE), Chongqing, China.

Yu, Z., & Xu, W. (2022). A meta-analysis and systematic review of the effect of virtual reality technology on users' learning outcomes. *Computer Applications in Engineering Education*, *30*(5), 1470-1484. https://doi.org/10.1002/cae.22532