Report

Virtual Reality in Education: State of the Art and Perspectives

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1. Introduction

In recent years, immersive virtual reality (IVR) has taken on an increasingly important role in the field of education, positioning itself as a technology capable of profoundly redefining the very concept of the learning environment.By creating interactive, multisensory, and simulated spaces, VR allows students to explore complex concepts experientially, providing access to situations that are difficult to replicate in the physical world. This has made IVR particularly appealing for learning in disciplinary fields such as natural sciences, medicine, history, or engineering. However, the use of VR in education cannot be seen as a mere technological transposition of content; it requires a rethinking of the theories and models that guide teaching. In this sense, various theoretical frameworks have been proposed to analyze and design virtual learning environments. Among the most influential is the ICAP model (Chi & Wylie, 2014), which distinguishes between different levels of student engagement—passive, active, constructive, and interactive—based on the cognitive processes involved. The CAMIL model (Makransky & Petersen, 2021), on the other hand, highlights the central role of immersion and agency in learning effectiveness. Other perspectives, such as constructivism, situated learning, embodied cognition, and experiential learning, find in VR a privileged environment for their application. From a design perspective, educational VR applications are characterized by four fundamental components: the sensory dimension, interactivity, narrative structure, and social dynamics. Visual and auditory components are widely adopted, while haptic feedback remains relatively rare. Most applications include forms of interaction, but only a few promote full-body movement or true narrative engagement. Collaborative or social experiences are still limited, despite VR's potential to create shared virtual environments inhabited by avatars. As for learning outcomes, the literature distinguishes between declarative knowledge (related to memorizing and reorganizing information) and procedural knowledge (related to application and problem-solving). Studies show that VR is particularly effective in acquiring both types of knowledge, especially when students are engaged in active, manipulative, or collaborative tasks. Moreover, a positive impact is observed on motivational and emotional aspects, with increased engagement, satisfaction, and interest in learning. However, challenges remain. The main obstacles to the widespread adoption of VR in education concern access costs, infrastructure requirements, cybersickness issues, excessive cognitive load, and the lack of teacher training. From a design perspective, many experiences are weakly anchored to explicit pedagogical models, merely exploiting technological potential without fully integrating it into teaching. Nonetheless, recent studies highlight promising trends, such as personalized experiences (through individualized feedback, navigation assistance, and adaptive interaction), gamification, the use of immersive social environments (e.g., educational metaverses), and increased involvement of teachers in co-designing learning environments. In this context, analyzing the factors that facilitate the acceptance of technology by students and teachers—based on models like TAM, UTAUT, or ECM—becomes crucial for understanding and supporting the integration of VR in educational systems. In conclusion, virtual reality represents a powerful resource for education, especially in contexts oriented toward action, manipulation, and collaboration. But to become truly transformative and inclusive, it is necessary to establish a design approach grounded in solid pedagogical foundations, invest in training for all involved actors, and ensure equitable access to resources. Only then can the full educational potential of virtual reality be realized.

2. Theoretical Framework and Reference Models

The application of virtual reality in education requires a deep reflection on learning theories and pedagogical models that can guide the conscious and meaningful design of virtual environments. VR is not just a technological tool, but a true medium that introduces new forms of relationship, interaction, and knowledge construction. One of the most commonly used theoretical references in recent literature is the ICAP model (Chi & Wylie, 2014), which distinguishes four increasing levels of cognitive engagement: passive (receiving), active (manipulating), constructive (generating), and interactive (dialoguing). The guiding principle of ICAP is that the greater the cognitive and social activity required, the deeper the knowledge changes. This model has proven particularly useful for classifying educational experiences in virtual reality, distinguishing between purely exploratory environments and those that stimulate active participation and collaborative dialogue. Alongside ICAP, the Cognitive-Affective Model of Immersive Learning (CAMIL) (Makransky & Petersen, 2021) emphasizes that the effectiveness of VR learning depends on two key factors: sense of presence and sense of agency. These two elements are facilitated by features such as a high degree of immersion, interactivity, and the fidelity of the virtual representation. According to CAMIL, meaningful learning occurs when the student feels present in the virtual context and perceives control over their actions within the environment. The literature also acknowledges a strong compatibility between VR and some established learning theories. In particular: Constructivism emphasizes the active role of the student in constructing knowledge through interaction with the environment. VR serves as an ideal space for exploration, manipulation, and meaning-making. Situated learning finds in VR a powerful ally to simulate authentic contexts in which students can immerse themselves in realistic professional scenarios or historical reconstructions. Embodied cognition values the role of the body and action in forming concepts: the ability to physically act in virtual space enhances understanding and memory. Flow theory and experiential learning highlight the importance of engagement and direct experience: well-designed VR can generate deep concentration states and transformative learning. Methodologically, models like TPACK (Technological Pedagogical Content Knowledge) provide a useful framework for understanding the effective integration of VR into teaching, focusing on the balance between content, pedagogy, and technology. Other approaches, such as design thinking, are emerging as strategies oriented toward co-designing student-centered learning experiences. Finally, regarding the acceptance and continued use of immersive technologies, several studies have been based on models such as the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), and the Expectation-Confirmation Model (ECM). These models highlight how factors such as perceived usefulness, ease of use, satisfaction, and alignment with expectations are key to encouraging the adoption of VR by students and teachers. In summary, the theoretical framework supporting VR-based education is broad and evolving. Integrating VR into educational processes requires a solid grounding in pedagogical and cognitive models that guide its use in an intentional, critical, and educationally oriented way.

3. Categories of IVR Environments and Modes of Interaction

One of the central aspects in designing VR-based educational experiences concerns the types of environments and the modes of interaction they offer to students. Educational experiences in VR can vary significantly in terms of engagement, interactivity, and degree of immersion, with important implications for learning effectiveness. A useful classification of VR environments is proposed by Drakatos et al. (2023), who identify three main categories: Passive environments, where the student takes on a mostly observational role, similar to watching a film or a 360° video. In these cases, interaction is minimal or absent, and cognitive engagement tends to be limited. Exploratory environments, which allow users to move freely through the virtual space, observing and navigating between objects, but with limited opportunities for direct interaction. Interactive environments, where the student can manipulate objects, intervene in the context, perform tasks, and modify the environment itself. This level of engagement is considered the most pedagogically promising, as it stimulates active, constructive, and dialogic learning. The literature identifies four key components in the design of educational IVR environments, known as immersive dimensions: Sensory: includes visual, auditory, and tactile components. Most applications leverage high-quality graphics and directional audio to create a sense of presence. Haptic feedback, though still rare, offers an additional opportunity for physical involvement. Action-based: concerns the ability to interact with the environment through gestures, movements, or direct manipulation. The most effective applications promote embodiment, where the body becomes a cognitive tool, making action an integral part of learning. Narrative: many VR experiences are based on contextualized scenarios and tasks, assigning the student an active role within a story or simulation. Narrative design is particularly important for fostering emotional engagement and situated understanding of content. Social: although still underexplored, the social dimension of VR includes the possibility of interacting with other users or virtual agents (e.g., digital tutors or intelligent avatars). Social VR technologies (like VRChat or metaverse environments) open promising scenarios for collaboration, exchange, and shared knowledge construction. To these elements are added advanced personalization features, which allow the experience to be adapted to individual student characteristics: autonomous navigation, immediate feedback, contextual assistance, avatar choice, adjustable difficulty level. These tools can enhance learning effectiveness, support self-regulation, and promote the inclusion of students with different needs. Finally, co-presence—the perception of sharing a virtual space with others—and self-presence—identification with one's avatar—are considered important levers for constructing meaning and identity in immersive learning contexts. The ability to represent oneself, interact, and collaborate in three-dimensional environments can radically transform relational dynamics and traditional teaching practices. In conclusion, the categories of environments and interaction modes offered by VR are multiple and layered. -Effective educational design must take these dimensions into account, balancing immersion, interactivity, narration, and sociality according to learning objectives and student profiles.

4. Application Domains of VR in Education

Virtual reality is progressively establishing itself as a cross-disciplinary educational tool, capable of adapting to a wide range of subject areas.Recent literature shows a growing spread of VR applications in educational contexts, particularly in higher education, but also extending to secondary and primary schools (AlGerafi et al., 2023). One of the sectors where VR has shown the greatest effectiveness is science and technology education, thanks to its ability to visualize abstract or invisible processes and simulate complex environments. In the biomedical field, for example, VR is used to teach anatomy, surgery, and emergency management, offering safe and repeatable experiences in high-fidelity environments. The ability to manipulate 3D organs, observe simulated procedures, or train in virtual operating rooms has been shown to improve procedural understanding and reduce errors in real-life contexts. In engineering, physics, and chemistry, VR environments allow students to experiment with scenarios that would require expensive or complex equipment. Through interactive simulations, students can build models, observe real-time physical dynamics, or explore chemical reactions, enhancing practical and visual learning. But the use of VR is not limited to STEM disciplines. Humanities and social sciences also benefit from immersive experiences, especially in contexts where spatial and temporal dimensions are central. In history teaching, for instance, VR allows exploration of reconstructed historical settings (such as ancient temples or past cities), promoting critical and contextualized learning. In geography, it is possible to simulate geological, climatic, or environmental phenomena, enhancing topographical and systemic understanding. In language learning, VR is used to create realistic communication contexts in which students can interact with virtual interlocutors, live everyday situations, and practice the language in simulated environments. This approach, known as situated learning, is particularly effective in promoting oral and pragmatic skills. Technical and vocational education is also integrating VR for training in specific contexts: from flight simulation to industrial management, from workplace safety to military training. In these fields, VR enables repeated practice in controlled environments, reducing risks and costs associated with practical training.Lastly, there is growing interest in using VR for teacher training, as shown by recent studies exploring virtual environments for distance teaching, co-working, collaborative design, and metacognitive reflection (Romano et al., 2023). In these cases, VR is not only a subject of instruction but also an environment for professional learning. In summary, the application domains of virtual reality in education are broad and constantly expanding. Its ability to create engaging, interactive, and contextualized experiences makes it suitable for different educational levels, disciplines, and modalities, paving the way for more effective, motivating, and personalized learning.

5. Learning Outcomes and Educational Impact

The effectiveness of learning in virtual reality has been the subject of numerous empirical studies, particularly analyzing the impact on cognitive, procedural, and affective outcomes. Available data consistently show that VR, when pedagogically grounded and well implemented, can offer significant advantages over traditional methods or less immersive technologies. One of the first aspects to emerge is VR's contribution to the acquisition of declarative knowledge, meaning knowledge related to facts, concepts, relationships, or rules. Well-designed immersive experiences improve memorization and conceptual understanding through the use of dynamic visual representations, active exploration, and multisensory engagement. In particular, studies such as that by Conrad et al. (2024) show that virtual reality can surpass the effectiveness of frontal lessons or videos in terms of information recall and organization. At the same time, the virtual environment proves highly effective for acquiring procedural knowledge, i.e., the ability to perform tasks or solve problems. Interactive simulations, operational experiences, and hands-on activities allow students to 'practice' in a safe and repeatable manner. The possibility of experimenting with complex scenarios, making mistakes, and receiving immediate feedback makes learning deeper and more effective, especially in professional or technical contexts. In addition to cognitive results, numerous studies highlight the motivational and affective benefits of VR. The immersive effect, direct interaction, and sense of presence contribute to increasing students' engagement, satisfaction, and enjoyment of learning. The playful dimension and gamification—where present—further enhance motivation, leading to more active and sustained participation. In particular, the study by Di Natale (2023) confirms that the alignment between expectations and perceived experience in VR supports students' intention to continue using these technologies in the future. However, IVR's impact varies depending on the level of engagement required: environments with bidirectional interactions, engaging narratives, and active roles stimulate more complex cognitive processes such as elaboration, reflection, and critical thinking (Chi & Wylie, 2014). Conversely, predominantly passive experiences (e.g., viewing 3D environments without interaction) show limited or no impact, especially in the long term. Another important factor that emerges is the duration and continuity of the experience. Many studies are based on one-shot, short, and isolated activities that limit long-term skill consolidation. Additionally, the novelty effect of the technology may temporarily mask real learning challenges. For this reason, some authors recommend longer and progressive instructional cycles, with moments of reflection, evaluation, and transfer to real contexts. In summary, virtual reality can produce significant cognitive, procedural, and motivational outcomes, provided that certain key principles are respected: student activation, interactive design, task contextualization, and integration into the learning path. Only in the presence of these elements is it possible to achieve authentic, lasting, and transformative learning.

6. Challenges and Barriers to the Adoption of VR in Education

Despite the growing enthusiasm for virtual reality as an educational tool, its large-scale implementation still faces numerous challenges. Barriers to VR adoption in education are not only technical or economic but often also cultural, organizational, and pedagogical. A first clear barrier is technological and infrastructural. Using VR requires specific devices (such as headsets, controllers, sensors), stable network connections, and suitable spaces for physical interaction. Additional issues include software compatibility, maintenance, and digital infrastructure security. Moreover, the rapid evolution of immersive technologies makes it difficult for educational institutions to maintain up-to-date and effective solutions, with the risk of quick obsolescence. Costs represent another significant obstacle.

Purchasing and managing hardware and software, along with the need for staff training and technical support, still make VR largely inaccessible for many schools and universities, especially in resource-limited contexts. In this regard, digital equity becomes a central issue, as lack of access risks exacerbating educational inequalities. In terms of usability, several studies highlight problems related to cybersickness (nausea, dizziness, disorientation), sensory overstimulation, and high cognitive load. Although these effects vary from student to student, they can compromise learning effectiveness or reduce the experience to a technically impressive but pedagogically sterile exercise. Design must therefore consider a balance between immersion and clarity, avoiding an excess of stimuli that could interfere with essential cognitive processes. Another challenge is teacher training. Often, teaching staff lack specific preparation to effectively integrate VR into their practice. Many experiences remain isolated experiments led by motivated individual teachers, without systemic support or clear pedagogical framing. The lack of shared guidelines, examples of best practices, and instructional design support limits the effectiveness and spread of these technologies. From a pedagogical standpoint, there is also a weak theoretical integration. Many applications focus on VR's technical potential (graphics, realism, interaction) without explicitly linking these choices to learning objectives or educational models. This can cause a misalignment between virtual activities and expected outcomes, reducing the impact of the immersive experience. Finally, there is cultural resistance to VR adoption by some educational institutions, which struggle to recognize it as a 'serious' technology compatible with traditional curricular approaches. Until the pandemic, many VR innovations were introduced more through student initiative or small experimental groups than through structured institutional strategies (Rojas & Sanchez, 2023). In summary, the challenges related to adopting virtual reality in education are many and interconnected. Overcoming them requires coordinated efforts on multiple fronts: solid pedagogical design, investment in infrastructure and accessibility, staff training, and technical and cultural support. Only in this way will it be possible to move from episodic use to systematic and informed integration of VR in educational contexts.

7. Emerging Trends and Future Perspectives

As virtual reality continues to establish itself as an innovative tool in education, recent literature highlights several emerging trends that are redefining its use, potential, and role within educational systems. These developments concern both technological evolution and the pedagogical refinement of immersive experiences, with important implications for future training. One of the most promising directions is personalized learning. Thanks to the integration of adaptive modules, artificial intelligence, and interaction-tracking systems, VR applications are becoming increasingly able to adapt to the individual needs of students. Personalized visual, auditory, and textual feedback, virtual assistants, navigation suggestions, and automatic difficulty adjustments are just some of the strategies already employed to make the experience more effective and student-centered (Marougkas et al., 2024). At the same time, we are witnessing a growing use of gamification elements aimed at increasing engagement, motivation, and persistence in study. Reward systems, level progression, virtual badges, and cooperative challenges are integrated into VR experiences to foster active involvement and a sense of achievement. This trend aligns with a vision of learning as an engaging and rewarding experience, capable of stimulating not only memory but also personal initiative. Another significant development is the experimentation with social VR environments and educational metaverses, where students and teachers can meet, interact, and collaborate in shared three-dimensional spaces. In these contexts, the use of realistic avatars, the perception of co-presence, and the ability to build environments and objects together foster cooperative and participatory learning modes, going beyond the limits of traditional or remote teaching. Recent studies show that such environments can strengthen the sense of belonging, the relational dimension of learning, and the development of transversal skills such as communication and problem-solving. At the institutional and curricular level, a more mature approach to integrating VR into educational paths is spreading, with attention to co-design. Teachers, content experts, and developers collaborate to build virtual environments aligned with educational objectives, based on learning theories, and oriented toward measurable outcomes. In this context, the teacher's role evolves from simple user to co-designer of the experience, actively contributing to defining content, dynamics, and assessments. From a technological standpoint, future perspectives include the development of increasingly lightweight, accessible, and mobile devices, such as standalone headsets that eliminate the need for wired connections or fixed stations. Moreover, the integration of VR with other digital tools (e.g., augmented reality, machine learning, learning analytics) opens up hybrid scenarios where learning occurs seamlessly between physical and virtual environments, between presence and distance. Finally, research on technology acceptance and adoption is contributing to a deeper understanding of the factors influencing the sustainable use of VR by students and teachers. Models such as TAM, UTAUT, and ECM emphasize the importance of perceived usefulness, ease of use, satisfaction, and confirmation of expectations. Thus, the focus is shifting from the mere introduction of technology to its meaningful and lasting integration into educational practices. Looking ahead, virtual reality is no longer seen as a 'niche' or experimental tool but as a strategic technology for the schools and universities of the future. It is capable of responding to the challenges of personalization, inclusiveness, and experiential learning. Its potential lies not only in immersive effects but also in the opportunity to radically rethink the spaces, times, and relationships of learning.

8. Conclusions

The review of the scientific literature on virtual reality in education reveals a rich, articulated, and evolving picture. Educational applications of VR have multiplied in recent years, showing a remarkable variety of uses, design approaches, and results. From university contexts to secondary schools, from technical to humanistic education, VR has demonstrated its potential to enrich the learning experience through immersive, interactive, and engaging environments. However, the full integration of virtual reality into educational systems requires a change in perspective: it is not about simply adding a technology to an existing framework, but about rethinking the spaces, times, roles, and goals of learning. In this light, it is essential that the adoption of VR be guided by solid theoretical models, coherent pedagogical design, and a strategic vision that includes infrastructure, accessibility, training, and support. VR's potential does not lie merely in its ability to impress or astonish, but in its capacity to build environments where students can explore, act, collaborate, and reflect. To achieve this meaningfully, it is necessary to overcome the identified challenges—technical, economic, cognitive, and cultural—through forward-looking educational policies and continuous research on the most effective practices. Current trends point to a future in which virtual reality will be increasingly personalized, connected, adaptive, and socially shared. It will no longer be an emerging educational technology, but an integrated, accessible, and pedagogically mature tool. In this scenario, the role of teachers as experience designers and students as active agents of their own learning will be central to fully harness the transformative potential of VR.

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