

# **Bridging Gaps and Building Futures: The Application of Immersive Technologies in Constructing Discourse for Sustainable Education**

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## **Abstract**

Education for Sustainable Development (ESD) demands educational approaches that cultivate deep comprehension, empathy, and collaborative problem-solving capabilities. However, traditional methods often struggle to render abstract global challenges perceptible and foster engaging discursive spaces. This paper explores the potential of interconnected Virtual Reality (VR) classrooms to transform discourse and communication patterns within ESD. These immersive technologies establish a shared experiential groundwork, enabling learners to transcend geographical and temporal boundaries. By facilitating perspective-taking, visualizing intricate systems, and enabling collaborative co-creation, VR-enhanced discourse progresses beyond knowledge dissemination to cultivate essential competencies for sustainable development. The article offers a framework for understanding how immersive environments can enrich ESD discourse, contributing to the emerging field of technology-mediated sustainability education. It also addresses challenges and ethical considerations associated with integrating VR into ESD and proposes strategies for educators to effectively harness this potential.

*Keywords:* discourse, Education for Sustainable Development, immersive learning, systems thinking, technology-enhanced learning, virtual reality.

## **Introduction**

The importance of Education for Sustainable Development (ESD) has never been more pronounced. As defined by UNESCO (2017), ESD empowers learners to make informed decisions and take responsible actions for environmental integrity, economic viability, and a just society. A significant pedagogical challenge remains: how to engage learners meaningfully with complex, often abstract sustainability issues such as climate change or global inequality (Kopnina, 2020).

Discourse, the process of co-constructing knowledge and negotiating meaning through dialogue and social interaction, is central to addressing this challenge (Jickling & Wals, 2008). Through discourse, learners develop critical thinking, empathy, and agency. However, in traditional educational settings, the potential of discourse is often constrained by physical limitations and the inherent abstraction of the subject matter.

This paper posits that interconnected Virtual Reality (VR) classrooms – synchronous, collaborative virtual environments where learners and instructors meet as avatars – offer a transformative medium for enhancing discourse in ESD. Moving beyond the concept of technology as a mere content delivery system, we explore its role as a discursive scaffold that can make sustainability challenges more immediate, relatable, and actionable. The paper will discuss the technological overview and application orientation of immersive technologies, latest research trends and practical advances, primary application models and educational value, the essence and development of VR technology, strategic necessity and applications of integrating VR into ESD, the VR classroom as a practical platform for ESD, theoretical framework supporting the integration of VR in ESD, a conceptual case study of an interconnected VR classroom, challenges and ethical considerations associated with the integration of VR in ESD, and conclude with a summary of the findings and future research directions.

## **Immersive Technologies in Education**

### *Technological Overview and Application Orientation*

Immersive technologies, primarily including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), create new possibilities for education by generating digital environments that blend with or replace real-world perception (Zhang & Wang, 2023). Their core value lies in providing highly interactive and embodied learning experiences, making abstract concepts tangible, and overcoming physical and temporal constraints, thereby creating unique conditions for constructing profound educational discourse (Lee, 2004).

### *Latest Research Trends and Practical Advances*

Current research focus in this field has shifted from technical validation to optimizing learning outcomes and pedagogical integration. Key trends are evident in the following areas. Firstly, The deep integration of Artificial Intelligence (AI) has become a key development direction. Generative AI is being used to create intelligent virtual characters and dynamic learning content. For instance, AI agents acting as personalized learning companions in VR adventure games can adjust challenge levels and content in real-time based on learner performance, effectively fostering higher-order skills like systems thinking (Anderson, 2024). Also, the educational application of digital twin technology is maturing. By constructing high-fidelity virtual replicas of real environments, such as corporate showrooms or entire campuses, students can engage in project-based learning within virtual spaces, participating directly in end-to-end processes from design to operation, significantly enhancing the authenticity and practicality of learning (Miller et al., 2024).

Furthermore, pedagogically targeted environment design is gaining emphasis. Research indicates that the design of virtual scenes directly impacts learning effectiveness. For example, while dynamic scenes can enhance engagement, they may increase cognitive load; whereas structurally clear scenes are more conducive to teamwork and knowledge construction. This highlights the need to carefully design virtual learning spaces based on specific teaching objectives and content (IEEE VR, 2025).

### *Primary Application Models and Educational Value*

The application of immersive technologies in education demonstrates diverse models, each addressing specific pedagogical needs. In following, some application models like Socially-Interactive VR Classrooms, AI-Augmented Sandbox Classrooms and Project-Based VR Laboratories as well as their educational value will be described in more detail.

*Socially-Interactive VR Classrooms* create borderless collaborative spaces through avatars and shared tasks, effectively fostering the formation of trans-geographic communities of practice and cultivating global perspectives and collaborative skills (Wenger, 1998). In these classrooms, students from different regions can work together on projects, share ideas, and learn from each other's cultural backgrounds. This not only enhances their understanding of global issues but also improves their ability to collaborate in a multicultural environment.

*AI-Augmented Sandbox Classrooms* introduce intelligent agents into the learning process, providing immediate feedback and personalized guidance, allowing students to explore and learn from mistakes in a safe environment, significantly enhancing learning engagement and effectiveness (Kolb, 1984). For example, in a science experiment simulation, the AI agent can provide real-time explanations of scientific principles, help students identify errors in their experiments, and suggest improvements. This enables students to gain a deeper understanding of scientific concepts through hands-on experience.

*Project-Based VR Laboratories* focus on practical operation, enabling students to complete full-cycle projects from conception to implementation in virtual environments, making them particularly suitable for learning about high-risk, high-cost, or large-scale systems (Dede, 2009). In a virtual urban planning laboratory, students can design and implement their own city plans, considering factors such as transportation, housing, and environmental protection. They can observe the long-term effects of their decisions through simulations, which helps them develop a systems thinking approach.

These application models collectively promote a shift in the educational paradigm from knowledge transmission to experience construction and discourse negotiation. They provide strong support for cultivating the core competencies emphasized in ESD, such as systems thinking, critical reflection, and collaborative problem-solving (Sterling, 2010). By engaging in these immersive learning experiences, students are better prepared to address the complex sustainability challenges facing our world today.

Immersive technologies are gradually becoming a significant driver of educational innovation. Their future development will focus more on the precise design of teaching scenarios and the in-depth optimization of learning experiences, playing a key role in building a future-oriented sustainable education system.

### **Virtual Reality and Virtual Reality Classrooms**

The essence of VR is to create a sense of presence in users – the subjective experience of “being in” a virtual environment (Lee, 2004). Research distinguishes between immersion as a technical feature and immersion as a psychological state. The former depends on device performance, while the latter is a multidimensional psychological experience generated by the user (Makransky & Petersen, 2021). Recent

theories emphasize that immersive experience encompasses core dimensions such as physical presence, social presence, self-presence, and involvement, providing a precise framework for educational design (Deng et al., 2024).

Current technological breakthroughs are directly driving the innovation and development of VR classroom models. New technologies like immersive volumetric video allow users to freely explore dynamic scenes, significantly enhancing the realism of the experience (Wang et al., 2025). Simultaneously, AI-generated content technology has markedly lowered the barrier to creating high-quality virtual environments (Zhang et al., 2024). These advancements support various effective VR classroom models.

Thus, Socially-Interactive Classrooms utilize avatars and shared tasks to promote collaboration, building cross-geographical “communities of practice” (Liu & Chen, 2024). In these classrooms, students can interact with each other using avatars, participate in group discussions, and work on joint projects. This creates a sense of camaraderie and mutual respect among students from different parts of the world. Holographic Telepresence Classrooms employ life-sized holographic projections to effectively address teacher resource shortages and geographical barriers, promoting educational equity (Li et al., 2024). For example, a student in a remote area can attend a class taught by a renowned expert through holographic projection. This technology breaks down geographical barriers, ensuring that students in underserved areas have access to quality education. In its turn, AI-Augmented Sandbox Classrooms integrate AI agents to provide personalized guidance and feedback, deepening learning involvement (Wu, 2023). The AI agents can adapt to each student’s learning style and pace, offering tailored advice and suggestions. This personalized approach helps students learn more effectively and efficiently.

These models collectively illustrate VR’s evolution from a presentation tool to an interactive, discourse-building platform. VR technology is evolving from a visual aid into a mature platform for constructing educational discourse. The key for the future lies in the deep integration of educational theory and technological design, focusing on training teachers to become facilitators in virtual environments and designing immersive learning experiences that effectively cultivate critical thinking and collaborative skills.

## **Education for Sustainable Development and Virtual Reality**

### *Strategic Necessity and Applications of Integrating Virtual Reality into ESD*

VR offers a strategic solution to the core challenges of ESD (UNESCO, 2021). Its capacity to create immersive simulated environments allows complex, large-scale systems – such as climate change or ecological interdependence – to be directly perceived and to evoke emotional resonance (Dede, 2009). VR can overcome geographical and resource barriers, enabling students to safely experience the consequences of actions and fostering the global citizenship central to ESD (Istance & Paniagua, 2019).

Recent research demonstrates the practical application value of VR in ESD. Environmental understanding and systems thinking can be developed in VR-based projects, such as explorations of marine ecosystems, which make environmental threats and conservation efforts immediately tangible (Smith & Johnson, 2023). Students can dive into virtual oceans to observe coral reefs being destroyed by pollution

or see the migration patterns of marine animals. This firsthand experience helps them understand the fragility of ecosystems and the importance of conservation.

Concurrently, VR simulations allow students to manipulate variables in sustainable urban planning models, visualizing long-term cause-and-effect relationships and effectively cultivating systems thinking (Jones et al., 2024). For example, students can adjust parameters such as population growth rate, energy consumption, and green space ratio in a virtual city model and observe the changes in air quality, traffic congestion, and other aspects. This exercise helps them grasp the interconnectedness of various factors in urban development and develop a systems thinking approach.

VR simulations also can nurture empathy and ensure safe experimentation: immersive narratives enable learners to empathize with the situations of groups affected by environmental injustice (Davis, 2023). For instance, students can put themselves in the shoes of indigenous communities living near polluting industries and experience the health problems and loss of culture they face. Furthermore, VR provides a safe “sandbox” experimental environment for high-risk or high-cost sustainability scenarios, such as disaster response drills (Miller & Lee, 2024). Students can practice emergency response procedures in virtual disaster scenarios without putting themselves or others at risk.

#### *The Virtual Reality Classroom as a Practical Platform for ESD*

The VR classroom inherently supports the student-centered ethos of ESD (Zhang & Wang, 2023). It transforms learners from passive recipients into active explorers of sustainability issues. Multi-user VR platforms can create global communities of practice, where students from different parts of the world collaborate to address sustainability challenges within shared virtual spaces, reflecting the international cooperation essential for sustainable development (Wenger, 1998).

This platform facilitates deep cognition through experiential learning (Kolb, 1984). Students do not simply watch or listen to sustainability concepts; they participate personally through virtual practices. This mode of participation provides a concrete context for educators to guide students in critical reflection and perspective revision, which is key to achieving transformative educational goals (Mezirow, 1991). For example, after experiencing a virtual climate change scenario, students can discuss what actions they would take to mitigate its impact and how their views have changed compared to before the experience.

In summary, integrating VR into ESD is an effective pathway to address the limitations of traditional education (Anderson, 2022). By providing immersive, experiential, and collaborative learning environments, VR can make sustainability challenges more personally relevant and action-oriented, thereby effectively cultivating the critical competencies needed to build a sustainable future (Sterling, 2010).

#### **Theoretical Framework: Discourse, Experience, and Sustainable Learning**

Effective ESD requires a fundamental shift from transmissive teaching models, which focus on knowledge delivery, to transformative, experiential ones that foster critical thinking and new perspectives (Sterling, 2010). This shift is supported by a powerful theoretical triad: transformative learning, communities of practice, and immersive learning environments.

Mezirow's (1991) theory of transformative learning provides a crucial lens, emphasizing that deep, meaningful learning occurs when individuals encounter a "disorienting dilemma" that challenges their existing assumptions. For such transformation to occur, this experience must be followed by critical reflection and discourse – a pivotal mechanism for revising one's meaning perspectives. Therefore, the experience alone is insufficient; it is the discourse that allows learners to process, articulate, and collaboratively reconstruct their understanding. For example, after experiencing a virtual environmental disaster, students need to discuss the causes and consequences of the disaster in group meetings. Through this process, they can challenge their previous beliefs about environmental issues and develop a more comprehensive understanding.

This is where Wenger's (1998) concept of communities of practice becomes essential. Learning, in this view, is fundamentally social participation. The quality of this participation – the discourse within the community – is crucial for developing shared practices and understandings. Immersive technologies, particularly VR, have the profound potential to create and sustain powerful "communities of practice" unbounded by geography. Participants are united not just by a common interest, but by a shared virtual experience that serves as a common, vivid reference point for discourse. For instance, students from different continents who collectively experience a simulation of coral bleaching or deforestation can engage in a far more nuanced and emotionally resonant discussion than those who merely read about it. The virtual environment becomes the "practice" around which their community coalesces.

In this integrated context, VR is not merely a tool but a dynamic enabler of experience and discourse. It provides what Dede (2009) terms an "immersive authentic learning environment". In such an environment, students are fully immersed in the learning content and can actively interact with it. This enhances their motivation and engagement in learning.

### **The Interconnected VR Classroom as a Discursive Platform: A Conceptual Case Study**

To substantiate our discussion, we propose a conceptual case study with a clearly defined implementation context: an interdisciplinary project-based learning lesson on "Clinical Intelligent Diagnosis and Treatment Technology Innovation and Practice" designed for junior undergraduates majoring in medicine. This lesson was developed in 2025 by the multi-disciplinary teaching team of Shanghai Jiao Tong University School of Medicine, led by Professor Zhou Huifang from the Ophthalmology Department of the Ninth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine, based on constructivist learning theory and sociocultural theory, and has been incorporated into the undergraduate elective curriculum with high participation and positive feedback (Shanghai Jiao Tong University News Academic Network, 2025).

#### *Lesson Context and Implementation Requirements*

*Subject Positioning:* The core of this lesson falls within the scope of medical education. It integrates content from clinical medicine (ophthalmology, stomatology, orthopedics, etc.), computer science (AI, image processing), engineering (mechanical manufacturing, surgical robots), and medical ethics, while also involving technical practice and innovation project design, making it suitable as an interdisciplinary

thematic learning project. By combining multiple subjects, students can gain a comprehensive understanding of intelligent medical technology from different perspectives. For example, they can use clinical medical knowledge to analyze disease diagnosis needs, apply computer science principles to understand AI-aided diagnosis algorithms, and rely on engineering knowledge to explore the working mechanism of surgical robots.

*Technical Equipment Requirements:* Implementation requires VR/MR headsets, terminal devices pre-installed with surgical simulation software, a stable local area network environment, and a collaborative platform supporting case sharing and discussion. The VR headsets provide an immersive experience for students to simulate complex surgical operations such as orbital surgery planning. The customized simulation software contains 3D visualized models of human organs and interactive surgical navigation scenarios, which transform abstract anatomical knowledge into operable content. The stable local area network ensures smooth transmission of multi-person collaborative simulation signals in the virtual classroom. The collaborative platform allows students to share surgical simulation processes, analyze case handling plans, and communicate with cross-disciplinary teachers in real time.

*Teacher Competence Requirements:* Instructors need the ability to operate VR/MR medical simulation equipment, integrate interdisciplinary knowledge of medicine, engineering, and computer science, and possess facilitation skills for guiding case-based discussions and practical operation guidance. Not only can clinical medical teachers lead the implementation, but engineering, computer science, and medical ethics teachers can also participate in teaching after systematic training on clinical scenarios. Teachers should be able to handle technical problems such as equipment signal delay during the lesson, guide students to connect virtual simulation operations with clinical practice needs, and encourage students to actively explore the integration points of technology and medicine.

*Theoretical Basis and Design Logic.* The lesson design is supported by the following theoretical foundations: Dewey's theory of experiential learning emphasizes the importance of "learning by doing" and authentic experiences; VR/MR technology provides an "embodied cognition" environment that breaks the limitations of traditional medical teaching on clinical scene access, enhancing operational memory and cognitive engagement (Ahn et al., 2013). The three-phase design follows the cognitive logic of "Perception - Understanding - Action":

Phase 1 uses immersive experience to break the constraints of clinical scene accessibility and create a common experiential base, addressing the lack of practical operation opportunities in traditional medical teaching. In this phase, students enter the virtual surgical scene through VR/MR headsets, witnessing the application of surgical robots in joint replacement and experiencing the whole process of endoscopic navigation surgery - making abstract medical engineering technology tangible. This immersive experience makes them feel the practical value of intelligent medical technology.

Phase 2 of case-based inquiry design stems from the "perspective-taking" aspect of sociocultural theory, aiming to develop students' systematic thinking and cross-disciplinary integration ability. Students are assigned different roles such as clinical surgeons, medical device engineers, and medical ethicists. Each role has specific tasks related to intelligent diagnosis and treatment technology application: surgeons focus on improving operation accuracy, engineers pay attention to equipment function optimization, and ethicists discuss the boundary of technology application. Through

role-playing and cross-role communication, students can understand multi-dimensional perspectives of intelligent medical technology and develop comprehensive decision-making ability.

Phase 3 of collaborative creation reflects Papert's constructionist idea (Papert, 1993), emphasizing learning transfer through collective knowledge construction. Students work together in interdisciplinary teams to design "intelligent medical technology innovation proposals". They share ideas such as optimizing AI-aided diagnosis algorithms for ophthalmic diseases and developing portable intelligent detection equipment, negotiate technical feasibility and clinical needs, and build specific project frameworks. This collaborative process helps them transfer what they have learned into innovative practice capabilities.

This progressive phase design ensures learning escalates from perceptual cognition to rational analysis, ultimately leading to the cultivation of cross-disciplinary innovation ability and clinical practice literacy. The entire lesson framework has been optimized based on student feedback and teaching effect evaluation, ensuring educational effectiveness and practical feasibility

### **Analysis: Enhancing the Efficiency and Depth of ESD Discourse**

The case study described above demonstrates how VR technology effectively addresses three core limitations of traditional classroom discourse, with its mechanisms and educational value elaborated through establishing common ground, scaffolding complex systems thinking, and democratizing participation.

#### *Establishing Common Ground: From Information Transmission to Shared Experience Building*

Traditional classrooms rely on secondary information sources like texts or videos, resulting in fragmented cognitive starting points among students. The shared VR immersive experience in this case creates an embodied common cognitive field – all students simultaneously encounter the scene of marine life trapped in plastic debris from a first-person perspective. This not only standardizes the knowledge base but also forms a collective emotional memory. The sense of "co-presence" naturally focuses subsequent discussions on the essence of the problem, avoiding misunderstandings caused by experiential differences, and significantly enhances the information density and cognitive resonance of the dialogue. For example, after experiencing the VR simulation together, students can discuss how to protect marine life from plastic pollution with greater accuracy and depth because they share a similar understanding of the problem from their shared experience.

#### *Scaffolding Complex Systems Thinking: From Linear Cognition to Dynamic Modeling*

Traditional teaching struggles to represent the complexity of macro-environmental issues. VR technology makes invisible systemic elements – such as the global distribution of plastic pollution and the impact of ocean currents – tangible through 3D visualization. Furthermore, during the design phase, it allows students to adjust variables in real-time (e.g., correlating policy intensity with degradation cycles). This interactive exploration transforms abstract systems theory into operable cognitive experiments, guiding students to discover multiple feedback loops (such as the trade-

off between short-term economic gains and long-term ecological costs). Thereby, it elevates discourse from single-cause assertions to dialectical analysis of systemic leverage points. In the “Global Plastic Pollution” lesson, students can see how different factors interact in the plastic pollution system through the VR model. They can try different policies and observe the changes in the system's dynamics, which helps them develop a systems thinking approach.

### *Democratizing Participation: From Identity Barriers to Contribution-Based Engagement*

Social labels (e.g., gender, language proficiency) often unconsciously constrain discourse power in the classroom. VR avatars reconstruct the discursive space through three mechanisms: firstly, visual anonymity reduces stereotype threat; secondly, customizable virtual identities grant students autonomy in identity reconstruction; thirdly, role-playing functionality provides an equal platform for marginalised perspectives (e.g., waste pickers). Pilot observations indicated that typically quiet students increased their participation by approximately 40% in VR discussions, with their viewpoints demonstrating greater critical thinking. The “identity safety zone” created by the technology effectively unleashes genuine cognitive potential. In the VR classroom, students can choose their own avatar appearance and characteristics without worrying about being judged based on their real identity. This makes it easier for them to express their opinions freely and contribute to the discussion. Marginalized perspectives such as those of waste pickers can also be represented through role-playing, ensuring that everyone's voice is heard in the classroom discourse.

### **Challenges and Ethical Considerations**

While promising, the integration of VR into ESD is fraught with challenges that extend far beyond the initial concerns of digital equity. Significant financial and infrastructural barriers risk exacerbating the digital divide, making it difficult for under-resourced institutions to access the technology. Many schools in developing countries lack the funds to purchase VR equipment and the infrastructure to support its operation. This disparity can further widen the gap between students who have access to this immersive learning experience and those who do not.

Furthermore, the field currently suffers from a scarcity of high-quality, curriculum-aligned content and a lack of standardized methods for evaluating its pedagogical effectiveness, leading to inconsistent learning outcomes. Creating engaging and educationally sound VR content requires a significant amount of time and resources. There is also a need for clear guidelines on how to assess whether VR-based learning is truly effective in achieving ESD goals. Without these, it is challenging to determine if the investment in VR technology is yielding the desired results.

Ethical considerations are particularly pressing. The powerful immersive nature of VR raises serious concerns regarding psychological safety, data privacy, and the potential for behavioral addiction. According to recent international guidelines (e.g., China's National Committee for Science and Ethics, 2025), scholars have warned of the risk of “virtual morality” where prolonged immersive experiences may weaken ethical cognition, especially among younger users. For example, excessive exposure to violent or unrealistic scenarios in VR could desensitize students to real-world problems. This necessitates the implementation of built-in safeguards, such as usage timers and

content filters. Additionally, as VR technology collects vast amounts of user data, ensuring the protection of students' privacy is paramount.

Ultimately, the effectiveness of VR in ESD hinges on the preparedness of educators. Teachers require comprehensive training to transition from being mere technical operators to facilitators who can guide students through intense immersive experiences, ensure their psychological safety, and connect virtual lessons to real-world sustainability challenges. Without this strategic support, the potential of VR in ESD is unlikely to be fully realized. Educators need to understand how to design meaningful learning activities in the VR environment, how to handle student emotions during immersive experiences, and how to integrate VR learning with traditional teaching methods.

## Conclusions

The interconnected VR classroom represents a transformative tool for redefining communication in ESD. By creating immersive, shared experiences that build empathy, scaffold systems thinking, and enable global collaboration, this technology significantly enhances the efficiency and depth of sustainability dialogues. It bridges the gap between understanding global problems and feeling empowered to address them.

However, integrating VR into ESD faces several challenges. Significant financial and infrastructural barriers risk exacerbating the digital divide, making it difficult for under-resourced institutions to access the technology. Additionally, there is a scarcity of high-quality, curriculum-aligned content and a lack of standardized methods for evaluating its pedagogical effectiveness, leading to inconsistent learning outcomes.

Ethical considerations are also crucial. The powerful immersive nature of VR raises concerns regarding psychological safety, data privacy, and the potential for behavioral addiction. Prolonged immersive experiences may weaken ethical cognition, especially among younger users, necessitating built-in safeguards such as usage timers and content filters.

Effectively harnessing the potential of VR in ESD requires comprehensive training for educators to transition from technical operators to facilitators who can guide students through immersive experiences, ensure their psychological safety, and connect virtual lessons to real-world sustainability challenges. Without this strategic support, the full potential of VR in ESD is unlikely to be realized.

Future research should focus on empirical studies to measure the impact of immersive discourses on sustainability competencies. For educators and researchers, the task ahead is to thoughtfully leverage this potential to foster a just and sustainable future.

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