Front. Digit. Educ., 2024, 1(2): 142–152
https://doi.org/10.1007/s44366-024-0001-3

REVIEW ARTICLE

Application of Immersive Technologies in Primary and Secondary Education

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Abstract The digital transformation is driving profound changes in education and teaching, with immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), representing the future form of the internet, set to lead a new round of innovation in primary and secondary education applications. This study first elaborates on the connotation and typical characteristics of immersive technologies, analyzes their potential applications in primary and secondary education scenarios such as space, resources, curriculum, models, and evaluation. It then points out the key issues in the application of immersive technologies in primary and secondary education from four aspects: educational system, innovative technology, application orientation, and privacy ethics. Finally, from the perspective of multi-party collaboration among government departments, educational entities, industries, and enterprises, we propose application strategies such as top-level planning and design, core technology research, typical case cultivation, and regulatory governance. Such strategies aim to promote the deep integration of immersive technologies and primary and secondary education, shaping a new educational climate that aligns with the talents demands of the digital era.

Keywords immersive technology, primary and secondary education, embodied interaction, education application

1 Introduction

The rapid advancement of technologies such as artificial intelligence (AI), Big Data, 5G networks, blockchain, virtual reality (VR), augmented reality (AR), and mixed reality (MR), among others, is driving the digital transformation of various socio-economic industries, leading to significant changes in productivity and lifestyle transformations (Haktanır et al., 2022). In contemporary times, new skill sets including human–machine collaboration, cross-disciplinary integration, computational thinking, and proficiency in effective communication and collaboration. These skill sets have become essential for nurturing talent in the evolving landscape (Ma & Hou, 2021). However, the promotion and implementation of the new skills still face various challenges. Amidst COVID-19 pandemic, challenges faced during the widespread adoption of online teaching platform, such as lack of immersion, low interactivity, and poor user experience, have resulted in a shift back to traditional teaching method in primary and secondary schools, with physical classroom remaining the primary instructional setting.

Rapid advancements in generative AI, immersive technologies, and interactive experiences are revolutionizing education by creating student-centered learning environments that transcend traditional spatial and temporal boundaries. In 2022, OpenAI introduced the ChatGPT large language models, representing a significant advancement in generative AI technology and its application (Aydin & Karaarslan, 2023). In 2024, OpenAI subsequently unveiled the Sora text-to-video model, capable of understanding and simulating real-world entities and operations, propelling AI development forward significantly and bringing society closer to a more intelligent future (Wang et al., 2024). In addition, technological progress, exemplified by products like Apple Vision Pro, showcases advancements in display, transmission, and spatial computing. The groundbreaking advancements integrate the digital content seamlessly into physical spaces, offer three-dimensional interactive visual experiences and novel immersive experiences. VR, AR, MR, and other immersive technologies, supported by brain-computer interfaces, the Internet of Things (IoT), and wearable devices, enable the deep integration of virtual and real worlds. Such fusion creates immersive, student-

Received April 15, 2024; accepted June 13, 2024

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centered teaching and learning environments that transcend spatial and temporal constraints, enhancing student cognition (Zhong et al., 2023). The multisensory, immersive, and interactive characteristics of these technologies are predicted to bring new experiences and paradigms to education (Jin et al., 2024).

In recent years, a plethora of scholars have embarked on an array of research endeavors exploring the utilization of immersive technology in educational contexts. For instance, Ali (2022), investigating the effectiveness of immersive technologies for future professional education, suggested VR as a versatile modular technology, particularly in medical field. Baxter & Hainey (2023) explored the diversity of immersive technologies and their application in higher education contexts, seeking to evaluate undergraduates' perceptions of how these technologies impact learning. Their findings revealed that the immersive technologies offered significant benefits though preference for face-to-face teaching remained popular among students. Turan & Karabey (2023), in their systematic review of the application of immersive technologies in distance education, specially focused on the significant pedagogical benefits of technology in higher education. However, the predominant focus of the existing studies on universities highlighted a lack of systematic investigation concerning primary and secondary education, which warranted a clearer delineation of their characteristics and application scenarios. This research aims to explore the connotation and typical characteristics of immersive technologies, analyze their application scenarios in primary and secondary education, identify key issues in their implementation, and propose strategies for their widespread adoption.

2 Connotation and Typical Characteristics of Immersive Technologies

Steuer (1992) pointed out that VR technology could create rich media environments, engaging students through visual, auditory, and tactile sensory systems, manipulating, responding to, and providing feedback on learning content. This gradual shift in student's perception from sensory immersion to cognitive immersion triggers deep experiential learning, making it easier to comprehend abstract concepts and complex operational processes. Dengel & Mägdefrau (2018) proposed that immersive learning, from a holistic learning perspective, involved engaging students in learning activities that evoked a sense of presence in the learning space. The main factors influencing learning outcomes include learning characteristics, perceptual experiences, cognitive processes, learning motivation, emotional state, and the application of educational media.

Immersive technologies encompass the utilization of computers, sensors, displays, and other devices to simulate a real or virtual environment, allowing users to experience a sense of presence (Ali, 2022). These technologies transcend physical space and the temporal linearity, facilitating the integration of the physical world, mental processes, and the objective realm of knowledge. They achieve the overlap and coupling of various scenes, such as traditional and modern, real and virtual, public and private environments, immersing students in these experiences. This immersion stimulates active engagement in learning, enhances cognitive abilities, nurtures empathy, and fosters knowledge associations, thereby prmotes positive learning outcomes (Wang et al., 2023). The typical characteristics of immersive technologies include presence, immersion, interactivity, and empathy.

Presence. This refers to the subjective experience in a learning space, where a heightened sense of presence correlates with the realism of the immersive environment. Immersive technologies craft a realm that not only mimics reality but, in some instances, surpass it, offering students a profound sense of presence.

Immersion. This denotes the depth of cognitive engagement, marked by a diminished perception of the real world and heightened identification with the learner's representation within the virtual educational setting. The strength of this immersion is contingent upon the quality of the immersive environment's media with sensory experiences, including vision, audition, somatosensation, olfaction, and gustation, further amplifying the effect.

Interactivity. Immersive technologies offer real-time response and feedback via natural human–computer interaction (HCI). This capability enables students to engage in independent and collaborative inquiry-based learning activities within an immersive educational environment, fostering the development of students' innovative awareness and application skills.

Empathy. This aspect gauges the ability to cognitively grasp and emotionally connect with others' perspectives. Within immersive environments, students can transpose emotional experiences to real-life contexts, thus enhancing empathetic skills through positive projections influenced by interactions with instructors, peers, or the environments.

Given the developmental stage of primary and secondary school students, immersive technologies exhibit divergent thinking, a robust inclination towards experiential learning, and wide-ranging curiosity (Rabillas et al., 2023). The aforementioned characteristics of immersive technologies, presence, immersion, interactivity, and empathy allow for the creation of an

integrated, multi-modal interactive learning space. This space offers highly engaging teaching models tailored for younger learners, sparking their imagination and creativity, sustaining motivational levels (Toumi et al., 2021), and facilitating context-specific, personalized, and gamified educational activities. Students can attain immersive learning experiences in this envrionment (Liao, 2023), cultivate innovative and critical thinking, and enhance advanced cognitive abilities, including memory, knowledge application, and problem-solving skills.

3 Immersive Technologies Reconstruct the Ecology of Primary and Secondary Education

The rapid advancement in immersive technology components, particularly exemplified by Sora, is poised to elevate immersive technologies in educational settings, shifting its focus from perception to cognition. This shift is expected to catalyze changes in primary and secondary education, encompassing the revolutions in teaching spaces, resources development, curriculum systems, pedagogical models, and evaluation paradigms. Consequently, a reconfiguration of the educational landscape will transpire, culminating in the establishment of a novel immersive educational ecosystem amalgamating tangible and virtual components.

3.1 | Building a Teaching Space of Virtual and Real Integration

Immersive technologies foster a multi-dimensional educational environment that seamlessly merges virtual and physical elements, thereby presenting expandable, innovative, and manipulable features. This integration facilitates the connection of diverse and multi-modal resources across disciplines, ensuring a smooth integration and real-time interaction between physical and digital realms. Catalyzing student-centered and inquiry-based learning, extensive information services, and embodied interactive experiences, these systems enrich the educational experience. By incorporating digital information into physical spaces, a harmonious coexistence of virtual and physical information emerges, substantially augmenting the students' understanding of the real world. Learners, equipped with VR, AR, and MR headsets, navigate between real and virtual environments, embodying either their real selves or digital avatars. Within the virtual space, scenes, models, or virtual peers can autonomously function and amalgamate with real-world information, facilitating coexistence and interaction. The abundant resource details and lifelike interactive features foster a profound sense of presence, crafting a genuinely immersive learning experience. The successful creation of such an integrated virtual and real teaching space hinges upon satisfying the criteria outlined in Table 1.

Immersive technologies integrate cognition, skills, and emotions into the interaction process between primary and secondary school students and their learning environments. This integration fosters a synergistic effect among psychology, sensory, and behavioral facets, dismantling the barriers that traditionally separate informational learning from experiential learning. For instance, primary and secondary science teachers can employ immersive teaching fields to offer multi-contextual learning spaces to students located in diverse settings. This approach facilitates autonomous inquiry-based learning scenarios, catering to the varied demands of scientific education, including experimental procedures, field trips, and creative inventiveness.

This enhances realism and engagement in learning, enabling students to more effectively comprehend and grasp scientific content and fostering scientific literacy. Students are immersed in personalized learning environments designed for individualized and tangible scientific learning activities. In these near-authentic, intricately designed scenarios, learners actively engage all their sensory pathways, dynamically

Table 1 Conditions for the blended teaching space of virtual and real integration

Key components of blended teaching space	Applications of immersive technologies
Embodied interaction	Smart technologies build immersive teaching and learning environments that support the full cognitive and emotional engagement of primary and secondary school students, thereby enhancing their engagement.
Perceptual fidelity	Utilizing sensors such as temperature, gas, humidity, sound, among others, real and virtual objects are perceived as they mapped to each other, activating the corresponding neural pathways in the brains of primary and secondary school students.
Repeat on demand	Repeat the personalized learning scenarios as needed to practice the operation steps with low cost and high safety to improve learning efficiency and operation proficiency.
Real-time feedback	Primary and secondary school students enter and exit the teaching space anytime, anywhere, and use the avatar to carry out social activities and get real-time feedback similar to that of the real world.
Emotional experience	Create the presence effect of coexisting real and virtual scenes, bring a panoramic social perception experience to primary and secondary school students, and provide a sense of presence that generates real emotional responses.

interacting with both the environment and available resources. This multi-dimensional immersion allows for a holistic acquisition of scientific knowledge and skills, cultivating critical attributes such as cognitive involvement, a scientific mindset, and practical innovation. Consequently, it elevates cognitive levels of students' comprehension, enriching their grasp of the fundamental tenets and inherent complexity of the scientific discipline.

3.2 | Integrating Multi-modal Interactive Teaching Resources

Teaching resources, as the means of production of education, serve as fundamental determants of the extent and character of education development. Immersive technologies subvert traditional primary and secondary school teaching resources, which are based on empirical and technical knowledge. This shift has generated 3D, highly immersive and freely innovative teaching resources. This advancement cultivates a comprehensive resource system that includes personal, institutional, communal, and corporate resources.

Additionally, it introduces diverse models of resource allocation, such as user-generated content (UGC), professionally-generated content (PGC), professional user-generated content (PUGC), and AI-generated content (AIGC), among others. Immersive teaching resources have the characteristics of higher realism, stronger interactivity, more convenient operation, and more timely feedback mechanism, which can better support free exploration, group collaboration, situational experience and other learning activities across the virtual and real space. They help primary and secondary school students realize immersive learning with more "flow" experiences (Pellas et al., 2021).

Immersive technologies have catalyzed a paradigm shift in the design of teaching resources, transitioning from the traditional educator-centered model to a collaborative framework with coalition of teachers and students. In primary and secondary education, teachers and students transition from mere passive recipients to proactive architects and innovators of immersive teaching resources. This transition enables the adoption of various production methodologies including individual creativity, collaborative group efforts, and intelligent machine-assisted productions. The resultant teaching resources are tailored to a wide range of scenarios, thereby transforming educational activities into processes that accommodate flexible teaching approaches, personalized learning trajectories, and dynamic content. This evolution addresses the multifaceted needs for innovation in primary and secondary school education.

Immersive teaching resources challenge the traditional model of one-way knowledge transmission, fostering interactive engagement and providing real-time feedback based on students' interactions. This personalized approach not only enhances learning efficacy but also cultivates a deeper interest in learning. For instance, the virtual experiment teaching service system developed by the Center for Educational Technology and Resource Development of the Ministry of Education of the People's Republic of China (National Center for Educational Technology, NCET) offers virtual simulation experiment resources that transcend limitations of time, space, and safety concerns. These resources facilitate the exploration of phenomena that are otherwise inaccessible due to constraints such as speed, danger, or environmental impact. Teachers leverage virtual environments to create immersive task scenarios, replicating real experimental settings and providing students with hands-on experiences. Through the manipulation of virtual tools and resources, students engage in interactive exploration, honing their experimental cognition and perceptual abilities. Immersive teaching resources, by offering customizable learning experiences tailored to individual learning styles and task requirements, empower students to deepen their understanding and mastery of subjects through highly realistic and interactive learning experiences.

3.3 | Creating a Hybrid Digital Curriculum

The paradigm of immersive teaching objectives and content is experiencing a significant shift from static stability to dynamic adaptability. Traditional pedagogical norms, emphasis on rote memorization of static knowledge, tailored to individual survival needs, are losing relevance in the digital society. Curriculum models centered on knowledge replication struggle to align with the evolving demands of talent cultivation in the digital era. Digital curriculum leveraging immersive technologies and deep learning are poised to disrupt the traditional decision-making processes in primary and secondary education. These curriculum, characterized by dynamic content and goals, offer high-quality services such as on-demand learning, personalized tutoring, and practical activities. Drawing on the unique characteristics of subjects in primary and secondary education, as well as the students' psycho-physical developmental stages, adaptive learning pathways constructed with AI tools facilitate diverse learning outcomes. Immersive experiences involve students in dynamic exploration and participatory knowledge construction, thereby amplifying the depth and breadth of learning outcomes (Rospigliosi, 2022). Teachers play a crucial role in creating three-dimensional, interactive, intelligent, and diversified teaching scenarios tailored to

the immersive learning environment. They design learning tasks to foster essential skills, scientific literacy, and practical competencies.

Hybrid digital curriculum designs, which integrate physical, mental, and emotional aspects, offer students authentic and enriching learning experiences, aligning with the fundamental goals of education. For instance, in a digital curriculum module on "Sewage and Wastewater Treatment," middle school teachers can flexibly utilize panoramic resources—"Wuhan Hanxi Sewage Treatment Plant," as depicted in Figure 1—to facilitate student learning. The immersive experience, featuring a panoramic visual scope and voice-guided narration, provides students with potent sensory stimuli, enhancing their understanding of ecological civilization protection. Students can navigate through virtual wastewater treatment facilities, gaining insights into infrastructural layout, operational principles, and ecological significance. This immersive exploration enables students to grasp the intricacies of wastewater treatment processes and appreciate the importance of water resource preservation and ecological sustainability.

3.4 | Providing a Highly Immersive Teaching Model

The temporal and spatial expansiveness, coupled with the human–machine integration capabilities of immersive technologies, empower primary and secondary school students to tailor their virtual and physical identities to suit their educational needs. These technologies facilitate navigation through diverse immersive teaching environments, allowing students to adopt different roles, and engage in synchronous, real-time interactive learning activities with peers across various fields and historical eras, enriching their emotional and experiential learning.

Interaction between students and the immersive teaching environment manifests in two ways: Firstly, students interact with scenes, models, and virtual avatars within the immersive environment using their real identities; secondly, students interact with peers, virtual avatars, scenes, and models with their virtual avatars seamlessly integrating into the immersive environment. Immersive technologies foster embodied participation and physical engagement, enabling students to observe, experience, and perceive multi-dimensional spatial scenes from various perspectives through their virtual avatars. By transcending the limitations of physical laws and geographical spaces, this modality enables comprehensive interaction with virtual and real objects, thereby facilitating bidirectional information exchange between the virtual and real worlds.

Immersive technologies also shape a teaching model wherein real and virtual teachers collaborate closely, maintaining the authenticity and interpersonal dynamics of traditional face-to-face teaching. For instance, immersive synchronous classroom teaching, as depicted in Figure 2, integrates real and virtual teacher avatars, facilitating precise content delivery,

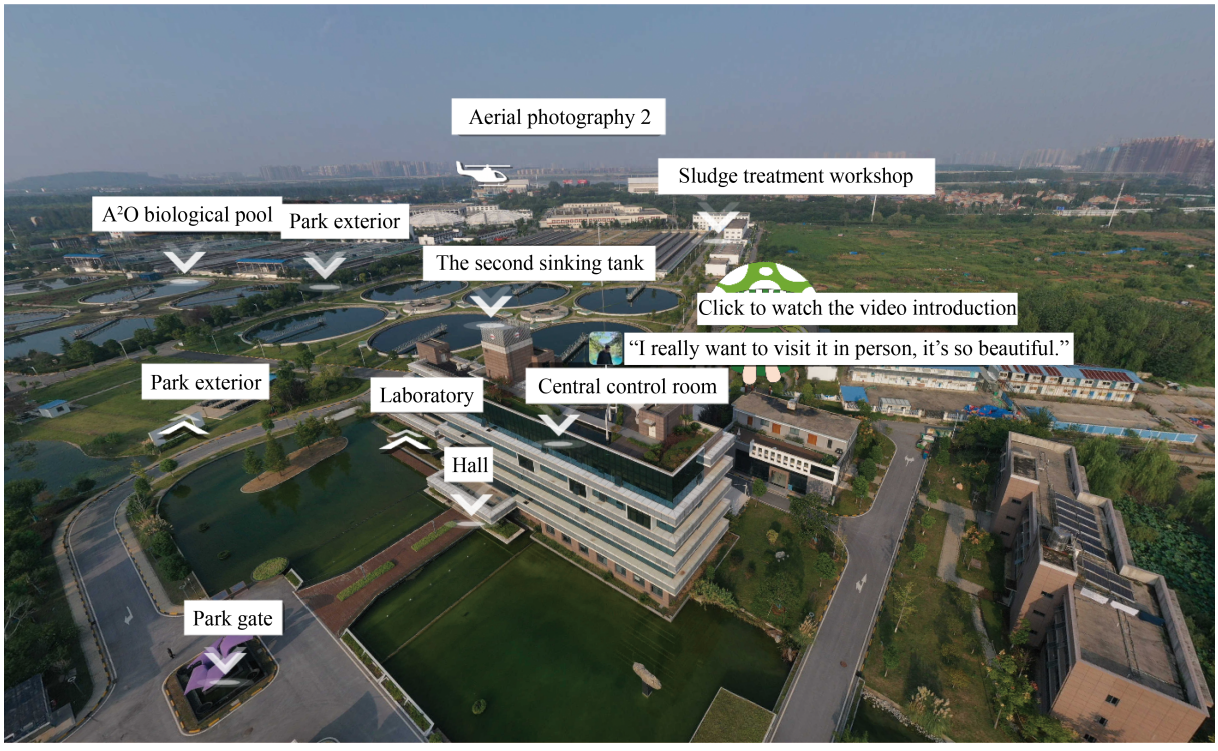

Figure 1 VR panorama of Wuhan Hanxi Sewage Treatment Plant.

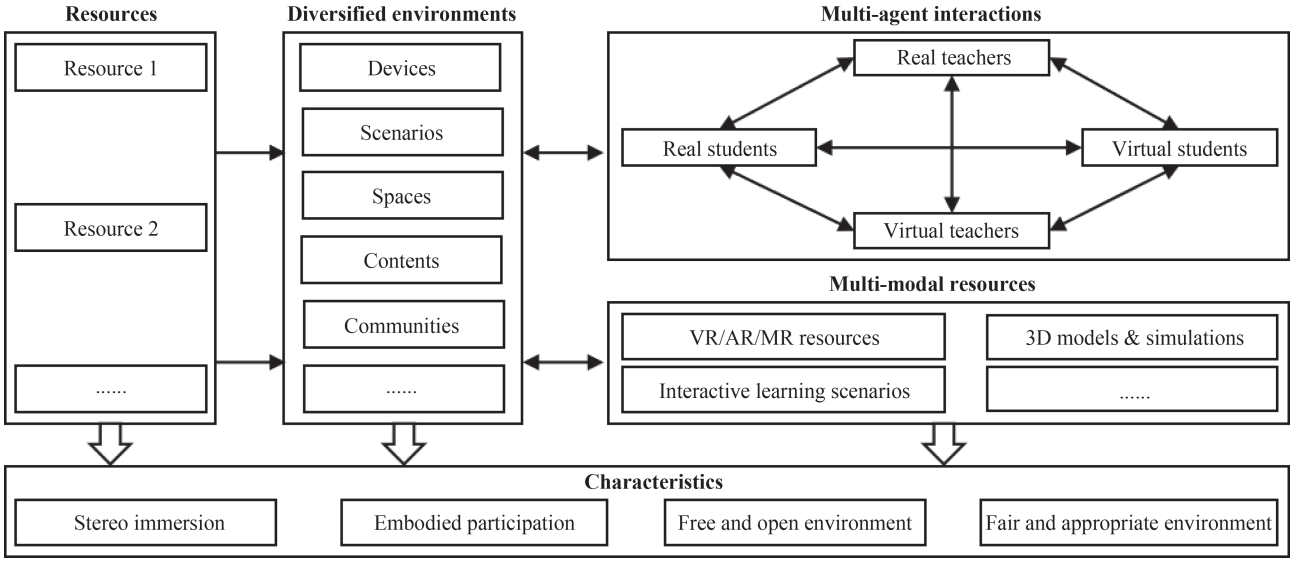

Figure 2 Immersive synchronous classroom teaching.

interactive engagement, and visualization of pedagogical processes. This model fosters dynamic teacher–student relationships conducive to multi-subject participation, transiting seamlessly between different teaching and learning modalities and facilitating bidirectional information exchange between virtual and real worlds. Furthermore, it aggregates geographically disperse students in a stereo-immersive, embodied-participation environment that is free, open, fair, and appropriate. Here, students engage in autonomous inquiry, collective collaboration, and situational experiences, capitalizing on an environment that fully exploits visual, auditory, and tactile sensory pathways. By doing so, the approach augments visualization, clarity, and concrete understanding of abstract concepts. Consequently, students enhance focus, persistence, and engagement in their learning endeavors.

3.5 | Forming a Data-Driven Teaching Evaluation

The cultivation of digital capabilities among future talents underscores the importance of information and data literacy, communication and collaboration skills, and digital content creation abilities. Immersive technologies offer an alternative to the one-dimensional assessment of holistic student prowess, instead enabling a multi-dimensional evaluation framework that extends vertically throughout the entire primary and secondary education continuum and horizontally across the spectrum of moral, intellectual, physical, aesthetic, and practical competencies. This sophisticated approach effectuates a transformative shift in assessment criteria.

Through comprehensive recording of the teaching process across various educational scenarios automatically and unobtrusively, immersive technologies continuously track the growth trajectory of both teachers and students in primary and secondary schools. This capability enables precise evaluation and effective interpretation of teaching phenomena, thereby enhancing the accuracy and analytical depth of educational assessments. In immersive teaching practice, the range of participating subjects extends beyond real individuals like teachers, parents, and peers to include a combination of real and virtual avatars. This expansion significantly enhances the scope, content, and methods of evaluation. It prompts a shift away from traditional evaluation methods, such as written exams and interviews, towards more open forms of assessment, such as activity-based and spatial evaluations. By embracing these open evaluation approaches, immersive teaching mitigates the influence of subjective biases on evaluation outcomes, thus enhancing the objectivity of educational evaluations.

Immersive teaching is characterized by its operational diversity and dynamic communication, facilitating natural interaction among students and various subjects and models within specific time, space, and subject contexts. This complexity underscores the need for data-supported and data-driven teaching evaluation at every stage. Leveraging technologies such as digital twin, data mining, and affective computing, alongside intelligent sensors, wearable devices, eye-tracking equipment, and other data collection tools, the teaching process captures and interprets multi-modal interaction data. This includes voical expressions, gestural cues, facial expressions, ocular movement, gaze patterns, and somatic sensations (Kang et al., 2024). By recording students' behavioral data in a three-dimensional, multi-spatial, and multi-dimensional manner, as illustrated in Table 2, immersive teaching enables the exploration of their hidden learning behaviors, diagnosis of learning outcomes, interests,

Table 2 Immersive learning behavior data

Data categories	Data comprises
Student attributes	Age, gender, school year, etc.
Learning performance	Learning frequency, duration, test scores, correct rate of task completion, operational proficiency, etc.
Learning resources	Learning context, domain concept, resource type, resource number, etc.
Behavioral characteristics	Learning action, behavioral location, concentration characteristics, etc.
Emotional state	Mood change, interest level, emotional engagement, etc.

physiological conditions, and psychological states. Consequently, educators can make timely adjustments to teaching strategies based on these data-driven insights. For instance, cognitive science-related theories and experimental methods offer valuable insights into the processes of perception, learning, and memory within students' autonomous and collaborative learning scenarios. By applying these methods, educators can generate learning profiles, conduct diagnostic analysis, offer intelligent resource recommendations, and provide guidance on learning paths tailored to individual students' needs within the immersive teaching environment. This personalized approach enhances student engagement and comprehension, fostering a more effective and efficient learning experience.

4 Issues in the Application of Immersive Technologies in Primary and Secondary Education

4.1 | Educational System

The educational system plays a pivotal role in driving the transformation of education through immersive technologies. However, the diversity of educational clusters, openess of educational resources, and fragmentation of educational activities within immersive teaching environments present challenges to management, allocation, and utilization of resources in primary and secondary education. Establishing comprehensive educational systems, such as the *Opinions on Vigorously Strengthening the Construction and Application of Online Education and Teaching Resources in Primary and Secondary Schools* and the *New Generation Digital Technologies and Their Empowerment of Educational Evaluation Reform*, is essential to regulate educational activities and behaviors in immersive teaching environments. These systems ensure the scientific utilization and effective distribution of educational resources, thereby promoting the sustainable development of immersive technologies in primary and secondary education applications.

As immersive technologies reshape primary and secondary curriculum systems, innovate teaching models, and transform evaluation methods, they encounter challenges such as the absence of corresponding subject curriculum standards, teaching guidelines, evaluation mechanisms, and management systems. Strengthening the top-level design of immersive technologies in primary and secondary education applications is crucial. This involves clarifying its core value orientation and developing related policy guidelines, and regulatory frameworks to reshape and transform traditional primary and secondary teaching approaches. By doing so, the widespread application of immersive technologies in primary and secondary education can be effectively and orderly promoted, ensuring their successful integration into educational practices. For example, various levels of government can coordinate and integrate diverse educational systems, formulate a top-down immersive education system for primary and secondary schools, and establish clear and scientific policy guidance. These combined efforts would reshape and transform traditional primary and secondary teaching forms, vigorously and orderly promoting the wide application of immersive technology in primary and secondary education and teaching.

4.2 | Innovative Technologies

The establishment and advancement of immersive technologies hinge on robust support from underlying technologies. The computing power network serves as the cornerstone for immersive technologies, necessitating accelerated construction of network infrastructure to achieve high efficiency, low transmission delay, high system capacity, and seamless device integration. These capabilities are essential for meeting the demands of ubiquitous intelligent connectivity, real-time deep interaction, and boundless immersive experience. The development of immersive teaching environments stands as a pivotal foundation for integrating immersive technologies into primary and secondary education applications. Recent advancements in deep learning tools like DALL-E and ChatGPT have facilitated the creation of virtual environments surpassing traditional computer-generated games and VR environments. This progress significantly enhances the efficiency and breadth of immersive teaching environment construc-

tion. However, algorithms may also give rise to a range of issues pertaining to equity, security, and suitability. For example, the continual collection of feedback data based on teachers' and students' basic profiles can pose a threat to data security. This encompasses jeopardizing the confidentiality of personal sensitive data, identity recognition information, and inferred user additional information. Therefore, it is crucial to enhance data security technologies to effectively protect user data security.

Moreover, the development of multi-modal teaching resources and the creation of diverse teaching subjects are pivotal concerns that must be tackled for the widespread implementation of immersive technologies in primary and secondary school education. Breakthroughs in key technologies, such as rapid modeling of super-large-scale virtual teacher and student avatars, intelligent generation of extensive teaching resources, and the intelligent integration of human–machine-field, are essential for driving profound changes in the paradigm, experience, and practice of primary and secondary education. These advancements will enable immersive technologies to revolutionize the educational landscape, empowering educators and learners alike with transformative teaching and learning experiences.

4.3 | Application Orientation

In the context of a blended virtual–real immersive teaching environment, tailoring multi-modal teaching resources, facilitating diverse educational activities, and catering to the specific educational needs based on the age, learning habits, and cognitive development stages of primary and secondary school students are foundational for the deployment of immersive technologies in education. Currently, the software and hardware ecology of immersive technologies is still evolving, and its interactive functionalities are complex. This complexity necessitates cross-sectoral collaboration among enterprises for the development of educational platforms, scenario construction, and content creation, confronting challenges related to interoperability and connectivity (Chen, 2022). Overcoming educational barriers across different levels and categories, and systematically organizing multi-modal educational resources to satisfy the varied learning demands of primary and secondary students in knowledge acquisition, skill-building, and competency-enhancing, are pressing issues.

Moreover, the profoundly immersive nature of the teaching environment has the potential to induce strong addictive tendencies due to its high level of immersion, embodied interaction, and compensatory effect on reality. Prolonged exposure to immersive teaching environments among primary and secondary educators and students may result in psychological disorders and behavioral issues, such as escapism, personality fragmentation, and mental confusion arising from excessive reliance on these environments. For example, students may experience difficulty in discerning between the virtual and real worlds, leading to confusion regarding their true identity and challenges in differentiating authentic personalities and emotions in real-life situations. This, in turn, can create obstacles in interpersonal relationships, communication, and identity formation (Kye et al., 2021). Therefore, it is crucial to establish preventive measures against addiction and regulate the duration and frequency of usage for educators and students to ensure the appropriate and sensible implementation of immersive teaching environments.

4.4 | Governance System

In the free and open immersive teaching environment, it is essential to establish a stable ethical and moral system to guide human civilization into the virtual world responsibly. The application of immersive technologies in primary and secondary education must prioritize social fairness and inclusiveness, catering to the diverse needs of teachers and students from various ethnicities, regions, and genders. This includes providing personalized teaching content and ensuring the interpretability of recommendation algorithms to prevent misleading educational decisions and activities. From the perspective of individual privacy, the use of immersive teaching environments by technologically advanced companies may raise concerns about personal data leakage, illegal data collection and storage, and other privacy infringements. It is crucial to strike a balance between data utilization and data security, strengthen privacy protection measures and identity safeguards to prevent corporate overreach.

Furthermore, from an ethical perspective, in an immersive teaching context that breaks through spatial and temporal boundaries, coexists with virtual and real elements, and offers high degrees of freedom, the identities of teachers and students in primary and secondary education are multifaceted, anonymous, and integrated. This can easily lead to risks of excessive freedom. When high freedom results in an immersive teaching environment with high anonymity, the potential for misappropriation of avatars, imitation of others' avatars, and confusion between real and fake identities may proliferate. The platform administrators cannot predict all user behaviors, which further threatens the physical and psychological safety of teachers and students. Thus, there is a pressing need to establish and enhance ethical guidelines to cultivate a human-centered, ethically sound, and orderly immersive educational environment. This environment

should foster correct values and worldviews among primary and secondary school students, helping them navigate through cultural outputs and false narratives with discernment and integrity.

5 Strategies for the Normalized Application of Immersive Technologies in Primary and Secondary Education

5.1 | Doing a Good Job in Top-Level Planning and Design

Education authorities must enhance top-level planning and design, striking a balance between technological rationale and societal value, and establish proactive strategies for implementing immersive technology in primary and secondary education. This involves creating development plans, action plans, and security measures from a strategic standpoint, and promoting the effective deployment of immersive technology. The authorities should also introduce specialized policy incentives, institute a multi-channel investment mechanism throughout society, and concentrate on backing technological innovations related to immersive experiences, application demonstrations, and financial subsidies to ensure the favorable, steady, and systematic advancement of immersive technologies. This necessitates coordinated planning and arrangement, reinforcing the development of industry standards for compatibility, transmission, and sharing to ensure the orderly progression, educational efficacy, and practical efficiency of immersive technologies. For example, harnessing the capabilities of the China National Information Technology Standardization Network, education authorities would achieve the standardization of learning system architecture, learning technology system architecture, immersive teaching framework, and the establishment of data interoperability standards through communication and collaboration with leading enterprises, industry associations, and primary and secondary schools. Educators in primary and secondary education should prioritize the functional application value of immersive technologies, delve into their application scenarios and practical strategies. They should further provide feedback on instructional effectiveness and enhancement requirements to governance bodies, thus ensuring that immersive technology genuinely benefits the teaching activities in primary and secondary education.

5.2 | Carrying out Core Technologies Research and Development

Leading enterprises, industry groups, and primary and secondary educational levels should join forces to pioneer advancements in technological innovation, the development of platforms, and scene creation. Initially, this collaboration should emphasize the reinforcement of modern infrastructure, including data centers, computing facilities, and networking hardware. Such measures are aimed at accelerating the incorporation of new infrastructure within the primary and secondary educational spheres, thereby facilitating the digital and intelligent evolution of the education sector (McCarthy et al., 2023). By implementing an integrated immersive teaching environment, underpinned by advanced technologies such as cloud computing, networking, data analytics, and end-user devices, it is possible to construct teaching resources that are multi-modal, personalized, and conducive to creativity, alongside providing intelligent tools for teaching assistance. This approach will comprehensively support a wide array of educational activities within primary and secondary schools, including experimental, moral, safety, and environmental education, effectively promoting an immersive learning experience that integrates teachers, technologies, and students. For instance, NetDragon Websoft Holdings Limited, a Chinese company, is actively engaged in the incorporation of cutting-edge technologies such as VR, AR, and MR into educational applications. The company has introduced products including the online smart education platform Edmodo Academy (EDA), Future Laboratory, and 101VR Immersive Classroom, with the objective of establishing a nearly authentic, interactive, and immersive three-dimensional learning environment for students. In addition, the company seeks to offer digitalized and systematized high-quality learning resources to consistently enhance the learning experience of students.

Furthermore, there should be an amplification in the investments towards the development of fundamental technologies, the initiation of pivotal research projects within immersive technologies, and a concentrated effort on transcending the limits of core frontier technologies. This includes the rapid creation of virtual avatars representing teachers and students on an ultra-large scale, the intelligent generation of extensive teaching materials, and the intelligent synchronization of human–machine-environment interactions. Such advancements will underscore the efficiency and efficacy of immersive technologies in educational settings. The integration of immersive visual experience, tactile feedback, sophisticated human–computer interaction, and other cutting-edge technologies can refine the costs associated with cloud, edge, and quantum computing, as well as data modeling. Enhancements to display terminals capabilities in terms of natural interaction, immersive visualization, and heightened realism, can significantly enrich the educational experience for primary and secondary

teachers and students, offering them authentic and unparalleled learning and engagement.

5.3 | Focusing on the Cultivation of Typical Cases

Primary and secondary schools should integrate high-level strategic plans with innovative application practices, emphasizing the development of exemplary teaching and learning scenarios, advancing immersive education theory and technological innovation through practical teaching applications. For instance, Wuhan Erqiao Junior Middle School in China actively investigates the mechanism of multi-party synergy, extensively researches on the fundamental principles of immersive teaching, and implements diverse textbook and research activities. This has led to the formulation of a distinct approach of advancing immersive classroom teaching, serving as an exemplar for the standardized model of integrating immersive technologies in teaching. By piloting applications of immersive teaching, exploring different modes of immersive technology in primary and secondary education, and leveraging accumulated experience for widespread implementation, teachers can be inspired to explore innovative immersive teaching strategies and methods. These will facilitate the transformation of teaching elements and the promotion of awareness and acceptance of immersive technology (Zhong et al., 2022). Furthermore, by identifying and addressing the diverse needs and application scenarios of teachers and students in various stages and subjects of primary and secondary schools, the application of immersive technology in education can be actively and cautiously promoted.

5.4 | Implementing Regulatory Governance Safeguards

Government departments should actively facilitate partnerships among enterprises, educational institutions, and other organizations to establish a multifaceted synergistic governance model. This model should leverage institutional innovation to enhance the normality and effectiveness of managing immersive teaching environments, ultimately establishing a governance system where systems, technologies, and emotions are closely intertwined.

Firstly, there is a need to advance the study and formulation of legal norms and regulatory systems for immersive technologies. This includes the establishment of a unified digital identity-based management system for primary and secondary teachers and students, a virtual campus management system governing scholastic operations, discipline-based curricula, the execution of teaching activities, and an education administration system focused on the development planning of virtual and real symbiotic education, diverse educational space layouts, and multidimensional education quality evaluations.

Secondly, there is a need to strengthen the supervision of immersive technology usage. For instance, primary and secondary schools can introduce systematic requirements, such as usage time limits, participation systems for immersive activities, and educational ethics, to enhance the self-control ability of students and prevent excessive immersion in virtual environments, ensuring the efficiency, stability, and transparency of immersive teaching.

Lastly, by formulating data security standards and authentication norms for immersive technologies and enhancing user privacy protection, the personal safety and informational security of teachers and students can be ensured. This allows their digital assets, credit ratings, virtual identities, and other immersive technologies to be freely exchanged in both physical and virtual spaces. This also enables the standardized and orderly regulation and guidance of the future development of immersive technology in primary and secondary education.

6 Conclusions

Immersive technologies harbor the capacity to unveil new realms of creativity and advancement, empowering individuals to perceive, conceptualize, and execute tasks previously deemed impossible. Within the realm of primary and secondary education, their application spans a wide array of contexts, including teaching environments, resources, curriculum frameworks, instructional methodologies, and assessment mechanisms. This integration fosters a more sophisticated and interactive educational services and experiences.

Despite the potential of immersive technologies is vast, current challenges concerning regulatory frameworks, practical applications, and ethical implications persist and demand further scholarly inquiry and resolution. The development of an immersive teaching ecosystem is still ongoing, and achieving its normalized and scalabile integration in primary and secondary education settings requires time.

Participants in the area of education must approach the impact of immersive technologies on primary and secondary education with careful consideration, rationality, and scientific scrutiny. Adopting an experimental methodology, while fully recognizing its potential benefits and hurdles, is crucial. There is a need for active exploration of viable methods and strategies to apply immersive technologies effectively in primary and secondary education. Such efforts are

essential for fostering the seamless amalgamation, innovation, and sustainable growth of immersive technologies within the educational landscape.

Acknowledgments This work was supported by the National Natural Science Foundation of China (Grant No. 62277024) and the Major National Science and Technology Project (Grant No. 2022ZD0117104).

Conflict of Interest The authors declare that they have no conflict of interest.

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