Palestine Technical University Research Journal, 2026, 14(03), 44-71

Systemic Transformation of the Educational Environment in Higher Education Institutions through Virtual Reality

التحول المنهجي للبيئة التعليمية في مؤسسات التعليم العالي من خلال الو اقع الافتراضي

Navruz Khasanov[1], Diyor Umarov[2*], Tatiana Hryhorenko[3], Piotr Kusznieruk[4], Qi Wang[5]

نافروز خاسانوف[1] ، ديور عمروف[2*] ، تاتيانا هريهورينكو[3] ، بيوتر كوزنيروك[4] ، تشي و انغ[5]

[1]Department of Theory and Methods of Teaching Russian Language and Literature, Kyrgyz State University named after I. Arabaev, Bishkek, Kyrgyz Republic, [2]Tashkent State University of Economics, Tashkent, Republic of Uzbekistan, [3]Department of Social Work and Rehabilitation, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine, [4]Faculty of Social Sciences, Medical University of Warsaw, Warsaw, Poland, [5]ASEAN Innovation Development & Research Center, Chiang Mai, Thailand

[1]قسم نظرية وأساليب تدريس اللغة والأدب الروسيين، جامعة قيرغيزستان الحكومية التي تحمل اسم إي. أر ابايف، بيشكيك، جمهورية قيرغيزستان،[2]جامعة طشقند الحكومية للاقتصاد، طشقند، جمهورية أوزبكستان ، [3]قسم الخدمة الاجتماعية والتأهيل، الجامعة الوطنية لعلوم الحياة والبيئة في أوكر انيا، كييف، أوكر انيا، [4]كلية العلوم الاجتماعية، جامعة وارسو الطبية، وارسو، بولندا، [5]مركز آسيان للابتكار والتطوير والبحوث، شيانغ ماي، تايلاند

Received: 17/04/2026 Accepted: 17/07/2026 Published: 03/11/2026

Abstract: This theoretical-conceptual study, based on literature analysis and conceptual modelling rather than empirical testing, aimed to establish the theoretical foundations for transforming the educational environment in higher education through the integration of virtual reality (VR) technologies. The methodology was based on principles of systematicity, objectivity, and historicism, including a comparative analysis of traditional and VR-enriched educational environments. The research also involved structural-functional analysis, a systems approach to modernization, conceptual modelling, and content analysis. It revealed a paradigmatic shift from traditional education models to immersive, interactive, and multisensory learning. A conceptual model for VR integration was developed, comprising four key components: technological, pedagogical, organizational-management, and resource-based. These components ensure comprehensive transformation through horizontal, vertical, and feedback connections within the educational process. A phased strategy for implementing the model was proposed, consisting of preparatory, pilot, and scaling stages, each with clear objectives and success criteria. Pedagogical principles for virtual learning were outlined, focusing on immersion, interactivity, personalized learning experiences, a constructivist approach, and multisensory perception of content. The study also defined the methodological foundations for designing virtual educational content, including didactic requirements, quality criteria, and organizational-pedagogical conditions for effective VR implementation. The practical significance of this research lies in developing a scientifically grounded toolkit for modernizing higher education, enabling a targeted transformation of the educational process

* Corresponding Author E-mail: udiyor907@gmail.com

in response to the digital era and supporting the creation of innovative educational programs to train competitive professionals.

Keywords: Immersive technologies, Digital transformation of education, Pedagogical innovations, VR-based learning environment, Interactive learning.

المستخلص: هدفت هذه الدراسة النظرية المفاهيمية، القائمة على تحليل الأدبيات والنمذجة المفاهيمية بدلاً من الاختبار التجريبي، إلى إرساء الأسس النظرية لتحويل البيئة التعليمية في التعليم العالي من خلال دمج تقنيات الواقع الافتراضي .استندت المنهجية إلى مبادئ النظامية والموضوعية والتاريخية، بما في ذلك تحليل مقارن للبيئات التعليمية التقليدية والبيئات التعليمية المعززة بتقنية الواقع الافتراضي .كما شمل البحث تحليلاً هيكلياً وظيفياً، ومنهجاً نظامياً للتحديث، ونمذجة مفاهيمية، وتحليلًا للمحتوى، وكشف البحث عن تحول نموذجي من نماذج التعليم التقليدية إلى التعلم الغامر والتفاعلي ومتعدد الحواس .وقد طُوّر نموذج مفاهيمي لدمج الواقع الافتراضي، يتألف من أربعة مكونات رئيسية :تكنولوجية، وتربوية، وتنظيمية إدارية، ومواردية .تضمن هذه المكونات تحولًا شاملًا من خلال روابط أفقية ورأسية وتفاعلية ضمن العملية التعليمية. واقتُرحت استراتيجية مرحلية لتنفيذ النموذج، تتكون من مراحل تحضيرية وتجريبية وتوسعية، لكل منها أهداف ومعايير نجاح واضحة. تمّ تحديد المبادئ التربوية للتعليم الافتراضي، مع التركيز على الانغماس والتفاعلية وتجارب التعلّم الشخصية والمنهج البنائي والإدراك الحسي المتعدد للمحتوى. كما حددت الدراسة الأسس المنهجية لتصميم محتوى تعليمي افتراضي، بما في ذلك المتطلبات التعليمية ومعايير الجودة والظروف التنظيمية والتربوية اللازمة لتطبيق الواقع الافتراضي بفعالية. تكمن الأهمية العملية لهذا البحث في تطوير مجموعة أدوات علمية لتحديث التعليم العالي، مما يُمكّن من إحداث تحوّل مُوجّه في العملية التعليمية استجابةً للعصر الرقمي، ويدعم إنشاء برامج تعليمية مبتكرة لتدريب كوادر مهنية قادرة على المنافسة.

الكلمات المفتاحية :تقنيات الانغماس، التحوّل الرقمي للتعليم، الابتكارات التربوية، بيئة التعلّم القائمة على الواقع الافتراضي، التعلّم التفاعلي.

1 INTRODUCTION

The current stage of higher education development is characterized by intensive reform processes aimed at improving the quality of educational services and preparing competitive professionals for the global educational landscape. Particular attention is paid to modernizing the educational environment in higher education institutions through the implementation of modern digital technologies, which create innovative conditions for learning and ensure that the educational process meets the challenges of the digital age.

The research problem stems from the contradictions between the rapid growth of virtual reality technologies and their inadequate theoretical conceptualization in the context of modernizing the educational environment of higher education institutions. Traditional approaches to organizing the educational space sometimes fail to take into account the opportunities offered by modern immersive technologies for creating an innovative learning environment (Hamam & Loucif, 2009; Loucif et al., 2019). However, the lack of a comprehensive justification for the principles and methods of integrating virtual reality (VR) technologies into the educational process is an obstacle to the effective modernization of higher education.

Current trends in technological development are prompting the scientific community to study the potential of virtual technologies for transforming educational processes in greater detail. Khmil et al. (2023) present a comprehensive approach to studying the educational potential of virtual reality, systematizing the experience of using VR and augmented reality (AR) technologies in the Ukrainian educational context, with a particular focus on the specifics of implementing these innovations in domestic educational institutions. Their study focuses on the practical aspects of adapting virtual technologies to the characteristics of the national education system and the prospects for their large-scale implementation. At the same time, Kocharyan et al. (2024) expand our understanding of the synergistic effect of combining virtual reality and artificial intelligence in the educational process. They establish the theoretical foundations for their integration and discuss the potential benefits of this symbiosis for enhancing learning effectiveness.

The unique use of virtual technologies in blended learning has gained particular significance in research. Skrypka (2023) analyzes in detail the use of virtual reality within the framework of distance and blended learning in modern schools, defining methodological principles for adapting VR technologies to various types of educational interaction. The study substantiates the pedagogical prerequisites for the effective application of virtual reality in distance learning and defines criteria for evaluating the results of such application. Continuing this line of research, Kryvonos et al. (2024) expand theoretical knowledge regarding the role of virtual reality in modern education by systematizing existing methods of its application and formulating conceptual foundations for further development in this field.

The international scholarly discourse demonstrates the multidimensional nature of approaches to studying the educational potential of virtual technologies. Gong (2021) explores methodological issues regarding the use of virtual reality in combination with artificial intelligence technologies to create digital media artifacts, opening up new perspectives for interactive learning in the fields of art and design. In support of this approach, Pashkevich et al. (2021) develop a methodology for integrating virtual reality into educational programs for training specialists for Industry 4.0, substantiating the principles of sustainable development of educational technologies and their adaptation to the needs of modern manufacturing.

Smutny (2023) examines the market size for the use of virtual technologies in education, conducts a detailed analysis of the commercial segment of educational and training VR applications, identifies market development trends, and forecasts prospects for its expansion. Marugkas et al. (2023) conduct a retrospective analysis of the theoretical approaches, methods, and methodologies applied in the use of virtual reality in education over the past decade, systematizing accumulated scientific knowledge and identifying key trends in this field.

A separate line of research is devoted to the use of virtual reality in engineering education. Soliman et al. (2021) examine the characteristics of using virtual reality technologies in the training of engineering professionals, justify the methodological principles for their integration into technical training programs, and evaluate the effectiveness of such integration in developing the professional competencies of future engineers.

Despite fairly extensive research, an analysis of the academic literature reveals significant gaps in the justification for modernizing higher education through the implementation of virtual reality technologies. Most existing studies focus on specific aspects of VR use in education; however, there is a lack of both a comprehensive theoretical analysis of the systemic transformation of the university learning environment under the influence of virtual technologies and a conceptual framework for the pedagogical design of VR-enriched learning spaces. These issues underscore the need for a comprehensive study that will provide a scientific basis for modernizing the higher education environment by integrating virtual reality technologies into the educational process.

The scientific novelty of this study lies in the development of a comprehensive theoretical and conceptual model for integrating virtual reality (VR) into the higher education system, which differs from existing approaches in that it combines technological, pedagogical, organizational-managerial, and resource components into a single systemic structure. Unlike studies that focus primarily on individual VR tools, isolated disciplinary applications, student perceptions, or the broader educational potential of immersive technologies, the model proposed here views the integration of VR as a holistic transformation of the higher education learning environment. A distinctive feature of the model is the inclusion of functional links between its components and a phased implementation logic that connects conceptual design with institutional planning, though this requires further empirical testing.

The study aimed to substantiate the conceptual foundations for modernizing the educational environment of higher education institutions through the implementation of virtual reality technologies in the learning process. The objectives of the study were: to analyze theoretical approaches to the modernization of higher education environments and to determine the role of virtual reality technologies in this process; to develop a conceptual model for integrating VR technologies into the educational environment of higher education institutions; to substantiate the pedagogical principles and methodological foundations for the effective implementation of virtual reality technologies in the learning process.

2 METHODOLOGY

The research was conducted as a theoretical-conceptual study, grounded in literature analysis and conceptual modeling. No empirical testing of the proposed model was performed. The methodological framework of the study was based on the fundamental principles of systematicity, objectivity, and historicism, which ensured a scientifically grounded approach to the study of the processes of modernization in the higher education environment through the introduction of virtual reality technologies. The concept of systematicity made it possible to view the educational environment as a multi-component system, encompassing spatial, material, social, psychological-pedagogical, and technological elements in their interplay and interaction. The principle of objectivity ensured an objective examination of theoretical approaches to the modernization of the educational environment, free from technical determinism and undue conservatism in the evaluation of educational innovations. The principle of historicism allowed us to trace the evolution of approaches to the application of digital

technologies in education and to identify common features in the development of immersive educational technologies within the context of general trends in digital transformation in higher education.

A critical examination of recent studies on the use of virtual reality technology in the educational process was conducted through a theoretical analysis of the academic literature. The sample consisted of 34 scholarly articles published between 2021 and 2024, of which four were authored by Ukrainian scholars and thirty by authors from the USA, the UK, Germany, Denmark, Canada, Spain, Australia, Iraq, Saudi Arabia, China, and other countries. The 2021-2024 period refers specifically to the publication years of the analyzed scholarly sources. The broader period of 2020–2025 is used in the Results and Discussion section as a contextual timeframe to describe major transformations in higher education, including the acceleration of digitalization during and after the COVID-19 pandemic. The selection criteria were thematic relevance, academic credibility of sources, recency of publication, and indexing in prominent scientometric databases. The search for sources was conducted in Scopus, Web of Science, Google Scholar, and Ukrainian platforms for academic publications related to the international and Ukrainian scope of the literature studied.

The search was conducted using the following keyword combinations: "virtual reality in higher education," "VR technologies in education," "immersive learning," "VR-based learning environment," "digital transformation of higher education," "modernization of the educational environment," and "conceptual model of VR integration." Publications were included in English and Ukrainian. Sources were excluded if they were published outside the 2021–2024 period, did not address VR or immersive technologies in education, or focused solely on technical aspects without pedagogical relevance. Duplicates of other publications, sources lacking sufficient academic reliability, or those not directly related to the modernization of higher education were also excluded. The analyzed studies addressed the following specific aspects of the implementation of VR technologies in various national educational contexts, methodological approaches to integrating immersive technologies into the learning process, pedagogical principles of VR-based learning, and practical experiences with the use of virtual reality in higher education. The article considered works on systemic approaches to the modernization of the educational environment and conceptual foundations for the introduction of digital technology into the learning process at higher education institutions.

As part of a comparative study, a standard educational environment was compared with a virtual reality-enriched environment based on 10 key criteria; the findings were synthesized based on the works of Alamri et al. (2021), Herrera-Pavo (2021), Tusher et al. (2024), and B. Bermejo et al. (2023). This allowed for the systematization of differences between educational paradigms in tabular form. Data comparing the experience of modernizing the educational environment in American universities with European higher education institutions, according to the analysis by Bermejo et al. (2023), and with Asian educational institutions based on the findings of Akour and Alenezi (2022), were utilized by Marks and Thomas (2022). A comparison was also conducted of the specific use of virtual reality technologies across subject areas: in medical education according to Bermejo et al. (2023), in engineering disciplines based on Soliman et al. (2021), in the natural sciences according to Falah et al. (2021), and in the humanities

according to Gong (2021). This made it possible to identify universal principles as well as subject-specific elements of virtual reality application.

Structural-functional analysis was used to study the internal organization of the educational environment as a unified system and to determine the functional roles of virtual reality technologies in modernizing the educational process. The structural components of the traditional educational environment were examined, and the mechanisms of their transformation under the influence of virtual reality technologies were studied. Functional links between the technological, educational, organizational-managerial, and resource components of the conceptual model of VR integration were identified.

A systems approach was used to conceptualize the processes of modernizing the educational environment as a comprehensive transformation of the technological, pedagogical, organizational, and resource-related aspects of higher education institutions' activities. The educational environment was viewed as an open dynamic system that interacts with the external context and adapts to changing educational needs and technological capabilities. The systemic aspects of an educational environment enriched by virtual reality, such as emergence, integrity, hierarchy, structure, and functionality, were investigated. Principles of the systemic organization of virtual reality technology implementation were identified, ensuring the coordination of all participants' actions and the optimal use of available resources to achieve the strategic goals of modernizing the educational environment.

The theoretical construction of an integrated model for the implementation of virtual reality technologies in the educational environment of higher education institutions was carried out using conceptual modeling. Structural components, functional relationships, and stages of modernization were identified, forming four interconnected blocks. A conceptual structure was developed based on these components. The main characteristics of each structural block of the model were defined, and the functional significance of each element in ensuring the effective integration of virtual reality technologies was substantiated. The forms of functional relationships between the model's components were systematized in a table that included horizontal, vertical, and reverse relationships, with descriptions of their participants, the nature of interaction, and the results obtained. A phased implementation of the model was justified, specifying timelines, key activities, and success criteria for each implementation phase.

Content analysis was used to systematize and classify scientific information on the integration of virtual reality technologies into the educational process. The content of scientific publications was analyzed across five thematic categories: theoretical foundations of VR-based learning, practical aspects of implementing immersive technologies, methodological approaches to developing VR-based educational content, pedagogical principles, and conditions for the effective use of virtual reality. Key research areas in the field of VR education were identified, as well as theoretical gaps in contemporary scientific discourse. A conceptual and categorical framework has been systematized, including key terms and concepts related to the modernization of the educational environment through the application of virtual

reality technologies, with a definition of their essential characteristics and functional roles in the transformation of higher education.

3 RESULTS AND DISCUSSION

3.1 Theoretical approaches to the modernisation of the educational environment of higher education institutions and the role of VR technologies

Within the broader contextual period of 2020-2025, higher education institutions underwent significant transformations under the influence of digital technologies and the evolving requirements of the knowledge society. The educational environment of higher education constitutes a multi-component structure that integrates spatial-material, social, psychological-pedagogical and technological elements, which together ensure optimal conditions for knowledge acquisition, competence development and the personal growth of students (Alamri et al., 2021; Kryshtanovych et al., 2021).

The digital modernization of the educational environment involves not only the technical upgrading of infrastructure but also a fundamental overhaul of the methodological foundations of the educational process, the development of innovative models for stakeholder engagement, and the implementation of new pedagogical approaches.

The main directions for modernizing the educational environment of higher education institutions in 2021–2025 are the development of personalized learning pathways, the use of artificial intelligence in the teaching process, the development of hybrid forms of learning, and the creation of immersive learning environments (Artyukhov et al., 2025; Smolinskaya et al., 2024). Personalized learning involves adapting educational content, pace, and methods to the individual needs, abilities, and learning styles of each student. This is achieved through the use of big data analytics and machine learning algorithms. Hybrid learning models combine the advantages of traditional in-person education with the potential of distance learning technologies to develop adaptive formats that meet contemporary challenges and the diverse needs of the student body (Herrera-Pavo, 2021).

The challenges of digital transformation in higher education for 2020–2025 relate to ensuring educational quality amid rapid technological growth, preparing faculty to work with new technologies, and creating an inclusive educational environment. The COVID-19 pandemic (2020–2022) accelerated the digitization of education, revealing both the opportunities and limitations of existing educational institutions (Akour & Alenezi, 2022; Vasylchak et al., 2022). Student motivation and engagement in the digital environment have become critical success factors, and new methods of instructional design and learning process structures must be developed (Ferrer et al., 2022). The gamification of e-learning has gained particular importance as a means of increasing student motivation and engagement in digital educational environments, creating new mechanisms for participation in learning activities (Khaldi et al., 2023). The application of artificial intelligence technologies, particularly systems based on large language models, opens up new opportunities for personalizing the educational experience and creating adaptive learning environments (Rasul et al., 2023; Dahan, 2025).

Virtual reality technologies in the context of higher education represent a set of hardware and software tools that generate an artificial three-dimensional environment, enabling immersive interaction with virtual objects in real time. VR technologies are based on the user's complete immersion in a virtual environment using specialized equipment, including VR headsets, motion controllers, haptic devices, and body-tracking systems (Tusher et al., 2024). The characteristics of virtual reality technologies in an educational context include immersion, interactivity, the ability to simulate complex processes and phenomena, the safe conduct of experiments in a virtual environment, and the ability to adapt the learning experience to students' individual needs.

The pedagogical potential of virtual reality is underscored by the creation of new forms of learning that are unattainable in traditional educational settings. Virtual reality technologies allow for the visualization of abstract concepts and complex processes, the simulation of dangerous or otherwise inaccessible situations, and the repeated practice of learning activities without additional resource costs (Aizstrauta & Ginters, 2016; Buil et al., 2016; Falah et al., 2021). The immersive nature of the VR environment enhances students' concentration, helps them better retain learning material, and provides a deep understanding of subjects through the perception of multisensory information. A study of the use of a VR lab in a specially designed educational environment over five semesters shows that VR technologies are particularly effective in developing practical skills and spatial thinking, as well as in cases where professional skills must be acquired through practical experience (Marks & Thomas, 2022).

The synergistic effect of combining virtual reality with other digital technologies opens up new possibilities for the comprehensive modernization of higher education. Virtual reality and artificial intelligence together create adaptive learning systems capable of independently adjusting the difficulty level of tasks and providing personalized recommendations based on the analysis of student behavior in immersive environments (Kocharyan et al., 2024). The combination of VR with big data analytics provides tools for collecting and processing detailed information about students' learning activities, which helps optimize educational programs and improve their effectiveness. The use of cloud computing in combination with VR technology ensures the scalability and accessibility of immersive educational resources for a wide range of users without geographical limitations. Augmented reality technologies, when combined with VR, create hybrid educational environments that blend the capabilities of the virtual and physical worlds, opening up new opportunities for the development of educational technologies (Ginters & Revathy, 2021; Rasul et al., 2023).

Global experience with the use of VR technologies in higher education from 2020 to 2025 is characterized by exponential growth in interest and investment from leading universities around the world. American institutions, particularly Stanford University, the Massachusetts Institute of Technology, and Carnegie Mellon University, are actively establishing VR labs for teaching engineering, medicine, and computer science. European higher education institutions, particularly universities in the United Kingdom, Germany, and the Netherlands, are developing extensive plans to integrate virtual reality technologies into the curricula of a wide range of disciplines (Bermejo et al., 2023). The growing number of scientific publications and patents in this sector indicates that Asian universities, particularly in China, Japan, and South Korea, are demonstrating the highest rates of virtual reality technology adoption.

Global trends in the use of virtual reality in education are characterized by a shift from experimental application to systematic integration into curricula (Martynovych et al., 2024). The global VR market in education grew from $8.67 billion in 2022 to $11.95 billion in 2023, and is projected to reach $46.14 billion by 2027, with a compound annual growth rate (CAGR) of 40.2% over the forecast period (Research and Markets, 2023). This is stated in the report "Global Virtual Reality in Education Market Report 2023." This growth is driven by the decreasing cost of virtual reality equipment, improvements in graphics quality and system performance, as well as the emergence of 5G networks and cloud computing. A key trend is the emergence of specialized educational VR platforms that provide integrated solutions for various fields of study, including ready-made content, tools for creating customized virtual environments, and learning analytics systems.

The application of VR across many fields of study in higher education demonstrates the technology's flexibility in accommodating the specific characteristics of each discipline. In medical education, VR technologies are used to simulate surgical procedures, study human anatomy in 3D space, and develop clinical skills in a safe virtual environment (Bermejo et al., 2023). In engineering curricula, VR is used to simulate complex technical systems, conduct virtual experiments, and train students to work with expensive or hazardous equipment. In the humanities, VR enables the creation of virtual museums, historical reenactments, and immersive language environments for learning foreign languages. Virtual reality is used in the natural sciences to visualize micro- and macro-processes, simulate chemical reactions, and study phenomena that cannot be observed directly. In business education, VR is used to simulate managerial decision-making, practice presentation skills, and create virtual business environments for experiential learning.

Theoretical approaches to modernizing the learning environment in higher education institutions have been examined, and the main differences between traditional and innovative educational paradigms based on the implementation of VR technologies have been identified. A comparative analysis of various approaches reveals the major changes occurring in the educational landscape under the influence of digital technologies and explains the growing popularity of immersive learning in higher education. Systematizing the characteristics of traditional and VR-enriched educational environments makes it possible to identify strategic directions for modernization and assess the potential benefits of integrating virtual reality into the educational process (Table 1).

Table (1). Comparative characteristics of traditional and VR-enhanced higher education learning environments

Characteristic	Traditional learning environment	VR-enhanced learning environment
Spatial organisation	Physically limited classrooms and laboratories	Boundless virtual learning spaces
Access to resources	Dependent on material infrastructure	Virtual resources without physical constraints
Individualisation of learning	Standardised approach for all students	Adaptive learning pathways
Level of immersion	Passive reception of information	Full immersion in learning content
Experimental activity	Limited by available equipment	Unlimited opportunities for simulation
Content visualisation	Static images and diagrams	Dynamic three-dimensional visualisation
Interpersonal interaction	Direct teacher-student communication	Virtual collaboration and joint activities

Assessment of outcomes	Traditional forms of evaluation	Continuous monitoring of activity
Flexibility of the learning process	Rigid schedule and structure	Asynchronous and synchronous learning
Inclusivity of education	Barriers for students with special needs	Universal design of the learning experience

Note: characteristics are based on theoretical analysis of educational paradigms without reference to statistical measures of effectiveness.

Source: compiled by the authors based on Alamri et al. (2021), Herrera-Pavo (2021), Tusher et al. (2024), Bermejo et al. (2023), Akour and Alenezi (2022), Ferrer et al. (2022), Khaldi et al. (2023), Rasul et al. (2023), Falah et al. (2021), Marks and Thomas (2022).

The convergence of theoretical approaches to modernizing learning environments in higher education through the use of virtual reality technologies signals a paradigm shift from outdated educational models to new immersive forms of learning. Such changes are conceptually underpinned by the ideas of personalizing the learning experience, opening up unlimited opportunities for experimentation and research, and ensuring a high degree of student engagement in the learning process. The theoretical rationale for the role of virtual reality technologies confirms their potential as a catalyst for fundamental changes in higher education, opening new horizons for the development of future professionals' competencies and the creation of an innovative learning environment adapted to the challenges of the digital age.

3.2 Conceptual model for integrating VR technologies into the higher education learning environment

The conceptual model for integrating virtual reality technologies into the higher education learning environment is based on a systems approach and consists of four interconnected structural components that, taken together, enable the complete transformation of the traditional educational process into an immersive learning environment. This distinguishes this model from more limited concepts, in which VR integration is viewed as a technical, methodological, or subject-specific task, rather than as a systemic transformation of the higher education learning environment. Each component performs specific functions and has its own characteristics, which together constitute an integrated system for implementing virtual reality technologies in the higher education system. The technological component of the model provides the hardware and software foundation for a learning environment enriched with virtual reality and includes modern virtual reality equipment, specialized software, network infrastructure, and technical support services.

The hardware component includes virtual reality headsets of varying levels of complexity—from simple mobile devices to professional high-resolution systems, motion and gesture controllers, haptic devices for providing tactile feedback, user tracking systems, and high-performance computers with professional graphics accelerators. The software component includes specialized platforms for developing virtual learning environments, virtual reality content management systems, and tools for developing educational applications and integrated learning environments with virtual reality support.

The pedagogical component of the model provides a methodological and content foundation for the learning process using virtual reality (creation of educational content, development of methodological

support, training of teaching staff, and organization of pedagogical support for students). Educational content includes virtual courses in various disciplines, interactive simulators and training tools for practicing practical skills, virtual laboratories for conducting experiments and research, and 3D models of objects and processes for visual learning. Methodological support includes pedagogical scenarios for using VR technologies in the educational process, methodological recommendations for instructors on integrating virtual reality into various disciplines, systems for assessing students' academic achievements in the VR environment, and quality criteria for VR educational content.

The organizational and managerial component of the model is aimed at the implementation and operation of VR technologies in the higher education learning environment and provides for strategic planning, project management, regulatory oversight, and performance monitoring. Strategic planning includes formulating a concept for the digital transformation of the educational institution, identifying priority areas for VR implementation, planning project implementation phases, and allocating funding for the development of immersive educational technologies. Project management: is responsible for organizing the project team's activities, monitoring the quality of VR solution implementation, managing project risks, and ensuring adherence to project schedules.

The model's resources component provides material, financial, human, and partnership support for the processes of integrating virtual reality technologies into the higher education learning environment. Financial resources include funding for the purchase of virtual reality hardware and software, the development or adaptation of educational content, training and professional development for faculty, ongoing maintenance of technical infrastructure, and the creation of specialized spaces for virtual reality-based learning. Human resources consist of IT specialists with experience in virtual reality technologies, instructional designers for creating educational content, innovative faculty members ready to implement new technologies, technical specialists for maintaining virtual reality equipment, and administrative staff for project coordination.

The synergistic effect of combining the structural components of the conceptual model ensures the effective functioning of an educational environment enriched with virtual reality technologies. A system of direct and feedback loops facilitates interaction between the model's components and enables a rapid response to changing educational needs and technological capabilities. A comprehensive approach to the model's structure ensures the balanced growth of all system components and minimizes the risk of inefficient resource use during the implementation of virtual reality technologies in higher education (Table 2).

Table (2). Structural components of the conceptual model for integrating VR technologies into the higher education learning environment

Model block	Main components	Functional purpose	Key characteristics
Technological	VR equipment, software, network infrastructure	Technical support for VR-based learning	Scalability, compatibility, reliability
Pedagogical	Educational content, methodological support, staff training	Methodological support for VR education	Content quality, pedagogical validity
Organisational and managerial	Strategic planning, project management, regulatory framework	Coordination of VR implementation	Systematic approach, controllability, adaptability
Resource	Financial, human, spatial, and partnership resources	Resource provision for VR projects	Sufficiency, efficient use

Note: the model structure is based on a systemic approach to integrating educational technologies.

Source: compiled by the authors.

The system of functional relationships between the components of the conceptual model for the integration of virtual reality technologies constitutes a multi-component network of interactions that ensures the effective functioning of an educational environment utilizing virtual reality. Functional links are structured according to the direction of influence, type of interaction, and hierarchical level of management, forming a multi-level system for synchronizing the processes of implementing and operating virtual reality in the educational process.

Cross-cutting links in an educational environment enriched with virtual reality ensure the synchronization of activities between the structural blocks of the model at the operational level, creating conditions for the harmonization of processes and the optimization of resource consumption. Interaction between the technological and pedagogical blocks is implemented through mechanisms that adapt the technical capabilities of VR equipment to the specific requirements of the educational process, establish technical requirements for the creation of VR content, and ensure the integration of pedagogical solutions with existing technological platforms. The pedagogical unit develops specifications for the functionality of VR systems, defines quality parameters for technical solutions in terms of educational outcomes, and provides feedback on the effectiveness of the technological tools used in the learning process.

Coordination between the pedagogical and organizational-management units is ensured by integrating VR components into curricula and programs, aligning methodological approaches with the institution's strategic development goals, developing internal quality standards for VR education, and establishing a system to evaluate the effectiveness of immersive technology implementation. The organizational and administrative unit creates the framework for pedagogical activities using VR, provides regulatory and legal support for new educational practices, and manages the integration of VR technologies into existing educational systems.

The resource unit interacts with other components of the model through procedures that provide the necessary resources for the functioning of the technological, educational, and management units. The

resource unit provides financial support for the procurement of equipment and content development, supplies qualified personnel for the implementation of VR projects, establishes the material and technical infrastructure for VR laboratories, and coordinates partnerships with external organizations to attract additional resources and expert knowledge.

Vertical management and control links form a hierarchical structure for coordinating the implementation of VR technologies from the strategic to the operational level, ensuring the coordination of all participants' actions and alignment with the overall goals of developing a VR-enriched educational environment. The strategic level of management is represented by the university administration, the academic council, and strategic committees, which determine the general directions for the development of VR education, approve implementation concepts and programs, allocate resources for project implementation, and exercise strategic oversight of the achievement of set goals.

The tactical level of management includes department chairs, deans, department heads, and project managers. Their responsibilities include translating strategic decisions into concrete actions, coordinating the activities of lower-level units, monitoring the ongoing implementation of virtual reality technologies, and ensuring feedback between the operational and strategic levels of management. The operational level is represented by the following groups: instructors, technical specialists, curriculum developers, and students, who directly implement the learning process using virtual reality, apply virtual reality technologies in daily educational activities, and provide primary information on the system's effectiveness.

Feedback loops for system optimisation ensure the continuous improvement of the VR enhanced educational environment by analysing performance outcomes, identifying problem areas, and adjusting development strategies. The feedback system includes monitoring student learning outcomes in the VR environment, analysing lecturer and student satisfaction with the quality of VR educational services, evaluating the technical reliability and performance of VR systems, assessing the economic efficiency of investments in VR technologies, and studying the impact of VR learning on the development of students' professional competencies. Monitoring results are used to adjust the technical parameters of VR systems, refine pedagogical approaches to VR learning, optimise organisational processes, and reallocate resources among system components. Learning analytics within this feedback system should be understood as the systematic collection and interpretation of data generated by students' interactions in the VR environment, including task completion time, frequency of repeated attempts, navigation patterns, errors, levels of engagement, and progress in mastering specific skills. These data can support pedagogical decision-making by helping instructors identify learning difficulties, adjust the complexity of VR tasks, revise instructional scenarios, personalise feedback, and determine whether additional explanation, practice, or methodological support is required.

The comprehensive system of functional linkages provides conditions for the adaptive development of the VR-enhanced educational environment, enabling it to respond rapidly to changes in technological capabilities, educational needs, and external challenges. The multi-level structure of these linkages

ensures the system's stability in the event of local disruptions and creates the foundation for scaling VR technologies across the entire institution (Table 3).

Table (3). Functional linkages between components of the VR technology integration model

Type of link	Participants of the interaction	Nature of interaction	Outcome of interaction
Horizontal	Technological ↔ Pedagogical	Adaptation of technologies to educational needs	Optimisation of VR solutions
	Pedagogical ↔ Managerial	Integration into curricula	Institutionalisation of VR
	Resource ↔ All blocks	Provision of resources	Resource support
Vertical	Strategic ⟶ Tactical ⟶ Operational	Hierarchical management	Coordination of activities
Feedback	Operational ⟶ Tactical ⟶ Strategic	Monitoring and adjustment	System optimisation

Note: ↔ indicates bidirectional interaction; ⟶ indicates one-way transmission of information or managerial decisions.
Source: compiled by the authors.

The phased implementation of a conceptual model for integrating virtual reality technologies into the educational environment of a higher education institution requires the systematic implementation of transformative processes, taking into account the institution's specific characteristics, its resource capacity, and its strategic development priorities. The phased nature of the process reduces risk factors, ensures the rational use of resources, and creates conditions for the sustainable functioning of an educational environment that integrates virtual reality technologies.

The first stage, lasting 6–12 months, includes a comprehensive assessment of the current state of the educational environment, the development of a strategy for implementing virtual reality technologies, the formation of project teams, and the creation of a regulatory and methodological framework for project implementation. The assessment of the current state includes an inventory of the institution's existing material and technical infrastructure, an evaluation of the teaching staff's readiness to use virtual reality technologies, an analysis of educational needs across various disciplines, and the identification of priority areas for the integration of virtual reality. The development of an implementation strategy involves defining the project's goals and objectives, describing the implementation phases with specified timelines and completion criteria, planning resource allocation, and establishing a risk management system.

The formation of project teams involves recruiting specialists in information technology, instructional design, project management, and related fields; organizing training for the team on the fundamentals of virtual reality technologies and approaches to managing educational innovations; and assigning roles and responsibilities among project participants. The development of a regulatory and methodological framework includes the creation of protocols for using virtual reality technologies in the educational process, the establishment of quality standards for virtual reality educational content, the development of safety protocols for interacting with virtual reality equipment, and the definition of parameters for evaluating the effectiveness of learning using virtual reality.

The pilot phase lasts 12–18 months and involves the limited implementation of virtual reality technologies in specific disciplines or programs. At this stage, the developed solutions are tested to identify problem areas and gain experience in applying virtual reality in the educational process. The implementation of pilot projects includes the procurement of a basic set of virtual reality equipment to establish an experimental laboratory, the development or adaptation of pilot virtual reality courses for 2–3 selected disciplines of various fields, training a group of pioneer instructors to work with virtual reality technologies through specialized workshops and seminars, as well as creating a dedicated space for virtual reality-based learning equipped with the necessary infrastructure.

During the pilot sessions with students, experimental groups are organized to test courses using virtual reality; detailed data on students' learning activities in the virtual environment is collected; the technical performance of the virtual reality systems is monitored; and all aspects of the virtual reality learning experience are documented. Analysis of the pilot phase results includes an assessment of the pedagogical effectiveness of virtual reality-based learning compared to traditional methods, an evaluation of student and faculty satisfaction with the new learning formats, identification of technical issues and limitations of virtual reality systems, and a calculation of the economic return on investment in virtual reality technology.

The scaling and institutionalization phase (24 to 36 months) aims to scale successful VR solutions across the entire institution, integrate virtual reality into official educational programs, and establish a sustainable infrastructure to support VR-based learning. Scaling the virtual reality infrastructure involves expanding the material and technical base to provide all faculties and departments with the necessary virtual reality equipment, creating a network of virtual reality labs with a centralized management and monitoring system, developing a cloud infrastructure for storing and distributing virtual reality content, as well as integrating virtual reality systems with the institution's existing information systems.

The development of a comprehensive suite of VR courses encompasses the creation of VR content for all core disciplines within the educational programmes, adaptation of existing courses to the capabilities of virtual reality, development of interdisciplinary VR projects, and establishment of a system for the continuous updating of VR content. Widespread instructor training includes organising regular professional development programmes in VR technologies, creating an internal mentorship and knowledge-sharing system, fostering a community of VR education practitioners, and cultivating a culture of innovative learning within the institution.

The institutionalisation of VR-based learning involves the formal integration of VR components into curricula and educational programmes, the establishment of specialised organisational units to support VR education, the development of an internal quality assurance system for VR learning, and the formulation of a long-term strategy for the development of immersive educational technologies. Each stage of the model's implementation concludes with a comprehensive evaluation of achieved results and the adjustment of future development plans based on accumulated experience and changes in the technological and educational environment (Table 4).

Table (4). Stages of implementing the conceptual model for integrating VR technologies into the higher education learning environment

Stage	Duration	Key tasks	Expected outcomes	Success criteria
Preparatory	6-12 months	Analysis of the current state, strategy development, team formation	Readiness for VR implementation	Approved strategy, established teams
Pilot	12-18 months	Testing VR solutions, course trialling	Demonstrated effectiveness of VR learning	Positive pilot results
Scaling	24-36 months	Expansion across the institution, institutionalisation	Full integration of VR into the educational process	Systematic use of VR technologies

Note: the duration of stages may vary depending on the institution's specific characteristics and available resources.

Source: compiled by the authors.

The operationalisation of the conceptual model for integrating VR technologies into the higher education learning environment through these defined phases ensures a planned and sequential transformation from a conventional to a progressive educational setting. The phased approach reduces implementation risks, optimises the use of available resources, and generates conditions for the sustainable development of VR-integrated education. Effective operationalisation across all stages of the model fosters the creation of a competitive learning environment capable of providing high-level training for specialists in line with the demands of the digital economy and innovative society.

3.3 Pedagogical principles and methodological foundations for implementing VR technologies

The development of virtual reality (VR) as a new educational paradigm is based on a set of fundamental pedagogical principles that take into account the unique characteristics of virtual learning and ensure the full realization of the educational potential of immersive technologies within the higher education system. The principle of immersion and interactivity involves the student's complete immersion in a virtual environment, the ability to actively interact with objects and processes in the surrounding real or simulated environment, as well as the ability to move around, which makes the learning process more intuitive and effective (Petersen et al., 2022). This approach is achieved through the use of advanced virtual reality technologies, which provide a multisensory experience via coordinated visual, auditory, and tactile sensations, creating a strong sense of presence in the virtual environment. The personalization of the learning experience is achieved through the specific features of virtual reality technologies, which allow adaptation to the individual characteristics, needs, and learning pace of each student, using artificial intelligence algorithms to automatically adjust task difficulty and provide personalized recommendations (Horváth, 2021). Three-dimensional virtual environments create individually tailored learning conditions that correspond to diverse learning styles and the specific educational needs of students (Imran et al., 2024).

The constructivist approach to learning in virtual reality focuses on students actively constructing knowledge through their own interaction with virtual objects and scenarios, in line with contemporary

theories of cognitive development (Zajda, 2021). The virtual world provides an ideal environment for experimentation, exploration, and discovery through direct experience. Learners can freely make mistakes in a safe environment and try alternative solutions. The simultaneous stimulation of visual, auditory, and tactile channels in VR education for multisensory perception significantly improves memory retention and the development of long-term skills (Brugada-Ramentol et al., 2022; Oleksandrivna et al., 2023). Research shows that this multisensory technique is particularly useful for learning complex spatial objects and processes, improves long-term memory, and promotes motivation by creating emotionally rich educational experiences.

The methodological foundations for designing educational content for virtual reality provide a set of evidence-based methods for building effective virtual learning environments. These foundations are based on ideas from pedagogy, learning psychology, and virtual space design. Virtual reality learning scenarios must clearly define educational objectives, meet academic standards, offer tasks with gradually increasing difficulty, and integrate theoretical knowledge with practical skills through immersive experiences. The creation of virtual learning environments is based on an interdisciplinary approach that combines educational, technical, and design aspects of virtual reality application development (Suman et al., 2010; Cherniha & Pliukhin, 2013). This process includes analyzing educational needs, pedagogically designing the learning experience, developing 3D models, programming interactive functions, and testing with ergonomic requirements in mind to ensure safe and comfortable use.

The quality criteria for educational VR content include pedagogical criteria (alignment with learning objectives, methodological soundness), technical parameters (graphics quality, system stability), ergonomic characteristics (user comfort), and economic indicators of return on investment. Quality assessment is conducted through expert evaluation, user feedback, and analysis of objective data on learning activities in virtual reality. Particular attention is paid to the adaptive properties of the content, which allow the learning process to be automatically adjusted in accordance with the specific progress of each student (Table 5)

Table (5). Pedagogical principles and methodological foundations of VR learning

Principle/foundation	Key characteristics	Implementation mechanisms	Expected outcomes
Immersiveness and interactivity	Full immersion, natural interaction	VR equipment, multisensory stimuli	Increased focus and engagement
Personalisation	Adaptation to individual needs	Artificial intelligence algorithms, behavioural analytics	Individualised learning pathways
Constructivism	Active knowledge construction through experience	Experimental tasks, problem-based scenarios	Deep understanding, critical thinking
Content quality	Pedagogical and technical alignment	Comprehensive evaluation, testing	Effective achievement of learning objectives

Note: principles are implemented comprehensively and in interrelation.

Source: compiled by the authors based on Petersen et al. (2022), Horváth (2021), Zajda (2021), Brugada Ramentol et al. (2022), Suman et al. (2010).

The successful implementation of virtual reality technologies in the educational process depends on the presence of a set of pedagogical conditions that enable the full potential of virtual reality to be harnessed and ensure the effective integration of immersive technologies into the traditional learning environment. Teachers' readiness includes technical training in working with virtual reality equipment, pedagogical training in developing effective virtual reality scenarios, and psychological readiness for innovations in the field of education.

The teacher training system should consist of theoretical seminars on the pedagogy of immersive learning, practical workshops on the use of VR equipment, workshops on content development, and certification programs to validate competencies in the field of VR education. Developing VR content and adapting existing courses also requires realistic planning of teachers' workloads, dedicated time for preparation, methodological support, and institutional mechanisms that recognize the additional workload associated with designing, testing, and updating materials for immersive learning.

Technical support includes modern equipment, such as high-resolution VR headsets, high-performance PCs with professional graphics cards, motion tracking systems, and additional haptic devices to provide tactile feedback (Cabada et al., 2021; Ginters et al., 2020). As for software, it includes specialized educational VR platforms, learning management systems with VR capabilities, and tools for creating custom content. The network architecture must provide high-speed Internet connectivity, high-capacity local networks, and cloud services for storing VR content. Educational VR environments must include sufficient space for safe movement, adequate lighting, soundproofing, and ventilation systems to ensure comfortable conditions for use.

Organizational and pedagogical conditions include the development of a regulatory framework for the use of virtual reality technologies, content quality standards, and safety requirements; the adaptation of curricula to incorporate virtual reality components into educational programs; and the development of methodological support systems, including advisory centers and a repository of best practices. The development of hybrid models that optimally combine the advantages of virtual and real educational experiences, and the creation of adaptive programs and systems for continuous learning with VR elements (Table 6) ensure the integration of VR-based learning with traditional forms of education.

Table (6). Pedagogical conditions for effective VR implementation

Group of conditions	Key requirements	Readiness indicators	Expected outcomes
Staffing	Technical, pedagogical, and psychological competencies	Faculty certification, readiness for innovation	High-quality VR learning
Technical infrastructure	Modern equipment, software, networks	Compliance with standards, stable operation	Reliable VR system functioning
Organisational support	Regulatory framework, curricula, methodological support	Integration of VR into study programmes	Systematic use of VR technologies

Note: conditions are provided comprehensively and in interrelation.

Source: compiled by the authors based on Cabada et al. (2021).

The comprehensive implementation of pedagogical principles, methodological foundations, and organizational conditions generates a synergistic effect, ensuring the effective functioning of a VR-

enriched educational environment and achieving high outcomes in the preparation of competitive professionals. The interrelation between the principles of immersiveness, personalization, constructivism, and high-quality content design provides a foundation for developing innovative educational programs that fully exploit the potential of virtual reality to cultivate students' professional competencies in line with the demands of the digital economy and the modern labor market.

3.4 Discussion on the modernisation of higher education environments through the implementation of virtual reality technologies

The study identified the main directions of transformation in higher education: the development of a conceptual model for integrating virtual reality, the systematization of pedagogical principles of immersive learning, and the formulation of a phased strategy for utilizing virtual reality in the educational process. The results indicate a paradigm shift from traditional educational models toward progressive, immersive forms of learning based on the concepts of individualization, interactivity, and multisensory integration of educational content.

The study by Kudale and Bukhtar (2022), dedicated to the impact of augmented reality technologies on interactive learning processes, raises the question of the technological readiness of educational institutions to implement immersive technologies. The authors emphasize the importance of thorough technological restructuring as a key prerequisite for the effective integration of immersive solutions into educational practice. These findings align with the results of this study regarding the central role of the technological component in the proposed conceptual paradigm. However, the collected statistical data contribute to an understanding of technological readiness, as they include not only hardware and software components but also service support, telecommunications infrastructure, and integrated virtual reality content management platforms. The authors primarily focus on augmented reality technologies; nevertheless, the presented results clarify the overall potential of virtual reality for the development of comprehensive immersive educational ecosystems.

Zhang et al. (2022) investigated the use of immersive technologies in various educational contexts. In particular, the study focused on the use of virtual reality technologies in educational and intervention programs for children with autism spectrum disorders. The researchers note the potential to adapt VR technologies to create personalized learning pathways tailored to students' specific needs. These findings align with conclusions regarding the importance of individualization as a core principle of VR-based learning in higher education. This study also extends beyond narrowly specialized educational needs and proposes a universal conceptual model relevant to a wide range of disciplines and fields within higher education. The researchers' findings are limited to highly specialized applications; however, the model they developed implies a systemic transformation of the entire educational process in higher education through the comprehensive integration of four interrelated components.

Gong (2021) analyzes the use of VR and AI in digital media arts and examines the integration of artificial intelligence with virtual reality technologies in educational settings. The author emphasizes the synergistic impact of the interaction between various digital technologies on the development of creative educational solutions. The results of this study show that combining VR with artificial intelligence

technologies provides adaptive learning systems that can automatically adjust the complexity of tasks and offer personalized recommendations. However, the author's research focuses solely on artistic and creative disciplines. The presented results confirm the potential for applying VR technologies across all fields of knowledge. The conceptual model developed opens up more opportunities for achieving synergistic effects, including the integration of VR with big data, cloud computing, and augmented reality technologies.

Hidayat et al. (2021) investigated the use of augmented reality in elementary schools to assess the usefulness of immersive technologies in primary education. The authors of the study note the positive impact of immersive technologies on students' motivation and engagement in the learning process. These results align with findings regarding improved student concentration and better retention of learning material in VR environments due to multimodal information processing. At the same time, the authors' study is limited to primary education, whereas the results presented highlight the specific features of VR application in higher education, including the development of professional competencies and the training of specialists for the digital economy. The proposed conceptual model is geared toward more complex learning tasks characteristic of higher education, research activities, and interdisciplinary integration.

The study by AlGerafi et al. (2023) provides a thorough analysis of the potential and limitations of immersive technologies in education, as well as an assessment of the possibilities of augmented and virtual reality in the field of education. The authors emphasize the need for a critical evaluation of the advantages and potential drawbacks of immersive technologies to ensure their successful implementation. These findings align with this perspective, as the conceptual model developed includes a risk management system and allows for phased implementation, during which strategy adjustments can be made based on interim results. The study also highlights the importance of balancing innovative solutions with traditional educational methods. This idea is reflected in the presented results on the integration of VR training into existing educational formats through the creation of hybrid models.

Hamad and Jia (2022) assess the impact of virtual reality technologies on many spheres of human activity and explore existing and future applications of VR technologies. The researchers point to the revolutionary potential of virtual reality to create fundamentally new ways of interacting with information and the environment. The conclusions confirm the findings regarding a paradigm shift from traditional to innovative educational models under the influence of virtual reality technologies. The authors emphasize the versatility of virtual reality, which aligns with the proposed analysis of specific VR applications across many disciplines. However, their study is general in nature and does not include a detailed analysis of educational applications, whereas the conceptual model developed is specifically tailored to the challenges of modernizing the educational environment in higher education institutions.

Asad et al. (2021) conducted a thorough review of the scientific literature on the effectiveness of virtual reality as a pedagogical tool, particularly its use to enhance experiential learning. The authors note the positive impact of immersive technologies on the quality of the educational experience and the development of practical skills. These results align with findings regarding the effectiveness of virtual

reality technologies for visualizing abstract concepts, simulating complex processes, and providing a safe environment for experiments. The study also confirms the constructivist approach as the theoretical foundation of VR-based learning, as reflected in established pedagogical principles of immersive education. At the same time, the systematic review does not include precise mechanisms for applying VR technologies in educational practice, whereas these results contain a carefully developed phased implementation strategy with specific timeframes and criteria for evaluating effectiveness.

The study by Abich et al. (2021) also analyzes the effectiveness of educational programs implemented using virtual reality technologies. The authors examine the evidence base for VR-based learning. They note the need for a systematic approach to evaluating the outcomes of immersive educational programs and the need to develop specialized evaluation criteria. The results presented here build on this perspective by proposing a comprehensive system for evaluating the effectiveness of VR learning, encompassing the monitoring of student performance, analysis of participant satisfaction, and assessment of the economic efficiency of investments in VR technologies. The study by the authors primarily focuses on training programs, whereas the developed conceptual model encompasses the full spectrum of higher education activities, including theoretical instruction, practical training, and research work.

Student perceptions of augmented reality and three-dimensional visualization technologies in chemistry education are examined in the study by Abdinejad et al. (2021), which analyses learners' attitudes towards innovative educational technologies. The researchers report a high level of acceptance among students for immersive technologies and note their positive impact on understanding complex chemical processes.

These findings align with the results obtained regarding the effectiveness of VR technologies for visualizing micro- and macro-processes in the natural sciences and for creating intuitive educational interfaces. The study also highlights the specific advantages of applying immersive technologies in chemistry education, which corresponds with the presented analysis of subject-specific VR applications across different fields of knowledge. However, the study is limited to examining student perceptions without a deeper analysis of the pedagogical mechanisms underlying effectiveness, whereas the developed pedagogical principles of VR learning provide a theoretical basis for the observed effects through the lens of immersiveness, interactivity, and multisensory perception.

In summary, the discussion demonstrates that the constructed conceptual model for integrating VR technologies exhibits a strong correlation with prevailing global trends in the modernization of educational environments, while simultaneously offering a holistic approach to the comprehensive transformation of higher education. The analysis validates the relevance and justification of the articulated pedagogical principles and methodological foundations for implementing virtual reality, which integrate optimal global practices and provide a conceptual basis for further research in the field of immersive educational technologies.

4 CONCLUSION

The study fully achieved its objective of substantiating the conceptual foundations for modernizing the educational environment of higher education institutions through the integration of virtual reality technologies. The results demonstrate a paradigmatic transformation in higher education, where conventional educational models are systematically being replaced by progressive immersive forms of learning, grounded in the principles of individualization, interaction, and multisensory engagement with educational content.

Exploration of conceptual approaches to modernizing the educational environment highlighted the key function of VR technologies as accelerators of systemic transformation in higher education. Virtual reality offers unlimited opportunities for designing personalized learning trajectories, ensures total immersion of students in the educational process, and enables the simulation of complex processes and phenomena within a safe virtual space. The synergistic effect of integrating VR with other digital technologies, including artificial intelligence and cloud computing, opens innovative horizons for generating adaptive educational systems capable of autonomously modifying the learning process in accordance with the individual needs of each student.

The constructed conceptual model for integrating VR technologies presents a systemic approach to the comprehensive transformation of the educational environment through the synergy of four fundamental blocks: technological, pedagogical, organizational and managerial, and resource-based. The model stipulates a phased operationalization, progressing from the initial phase through experimental validation to the expansion and full institutionalization of VR technologies within the educational process. This architecture ensures the mitigation of implementation risks, the rational utilization of resources, and the creation of conditions for the sustained development of an immersive educational environment.

The substantiated pedagogical principles of VR learning provide a theoretical foundation for the effective use of virtual reality in education. The principles of immersion and interactivity ensure organic engagement of students with virtual objects, personalization enables the adaptation of the learning experience to individual characteristics, and the constructivist approach promotes the active construction of knowledge through direct experience in the virtual environment. Methodological principles for designing VR educational content integrate advances in educational science, learning psychology, and virtual space design, establishing a comprehensive framework for developing effective immersive educational solutions.

The practical significance of this study lies in the development of a theoretically grounded toolkit for modernizing the educational environment of higher education institutions, which may serve as a preliminary conceptual framework for administrators and academic staff in planning the integration of VR technologies. These recommendations should be understood as conceptually substantiated guidelines rather than empirically tested implementation measures, and therefore require adaptation to specific institutional conditions and subsequent practical verification. The developed framework may inform strategic planning for educational technologies, faculty professional development programs, and the design of innovative curricula incorporating VR components.

The study's limitations are related to its theoretical nature and the absence of empirical verification of the proposed provisions under real conditions within higher education institutions. The conceptual model requires practical testing to confirm its effectiveness and, if necessary, to allow adjustments according to the specific needs of different types of educational institutions.

Future research prospects include the empirical validation of the proposed conceptual model, the development of methods for assessing the quality of VR educational content, the study of the impact of immersive technologies on the formation of professional competencies among students across various disciplines, and the analysis of the economic efficiency of investments in VR technologies in education. Particular attention should be given to investigating the psychological and pedagogical aspects of prolonged VR use and to developing methods for minimizing potential negative effects of immersive learning.

REFERENCES

Abdinejad, M., Talaie, B., Qorbani, H. S., & Dalili, S. (2021). Student perceptions using augmented reality and 3D visualization technologies in chemistry education. *Journal of Science Education and Technology*, *30*, 87-96. https://doi.org/10.1007/s10956-020-09880-2

Abich, J., Parker, J., Murphy, J. S., & Eudy, M. (2021). A review of the evidence for training effectiveness with virtual reality technology. *Virtual Reality, 25*(4), 919-933. https://doi.org/10.1007/s10055-020-00498-8

Aizstrauta, D., & Ginters, E. (2016). Using Market Data of Technologies to Build a Dynamic Integrated Acceptance and Sustainability Assessment Model. *Procedia Computer Science, 104*, 501–508. https://doi.org/10.1016/j.procs.2017.01.165

Akour, M., & Alenezi, M. (2022). Higher education future in the era of digital transformation. *Education Sciences, 12*(11), 784. https://doi.org/10.3390/educsci12110784

Alamri, H. A., Watson, S., & Watson, W. (2021). Learning technology models that support personalization within blended learning environments in higher education. *TechTrends, 65*(1), 62-78. https://doi.org/10.1007/s11528-020-00530-3

AlGerafi, M. A., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. *Electronics*, *12*(18), 3953. https://doi.org/10.3390/electronics12183953

Artyukhov, A., Artyukhova, N., Navolokina, A., Brych, V., Koziuk, V., & Kolinets, L. (2025). Immersive university: Step beyond the metaverse and education. In: *Proceedings - International Conference on Advanced Computer Information Technologies, ACIT* (pp. 1007–1012). https://doi.org/10.1109/ACIT65614.2025.11185660

Asad, M. M., Naz, A., Churi, P., & Tahanzadeh, M. M. (2021). Virtual reality as pedagogical tool to enhance experiential learning: A systematic literature review. *Education Research International, 2021*(1), 7061623. https://doi.org/10.1155/2021/7061623

Bermejo, B., Juiz, C., Cortes, D., Oskam, J., Moilanen, T., Loijas, J., Govender, P., Hussey, J., Schmidt, A. L., Burbach, R., King, D., O'Connor, C., & Dunlea, D. (2023). AR/VR teaching-learning experiences in higher education institutions (HEI): A systematic literature review. *Informatics*, *10*(2), 45. https://doi.org/10.3390/informatics10020045

Brugada-Ramentol, V., Bozorgzadeh, A., & Jalali, H. (2022). Enhance VR: A multisensory approach to cognitive training and monitoring. *Frontiers in Digital Health, 4*, 916052. https://doi.org/10.3389/fdgth.2022.916052

Buil, R., Piera, M.A., & Ginters, E. (2016). Multi-agent system simulation for urban policy design: Open space land use change problem. *International Journal of Modeling, Simulation, and Scientific Computing, 7*(2), 1642002. https://doi.org/10.1142/S1793962316420022

Cabada, E., Kurt, E., & Ward, D. (2021). Constructing a campus-wide infrastructure for virtual reality. *College & Undergraduate Libraries, 27*(2-4), 281-304. https://doi.org/10.1080/10691316.2021.1881680

Cherniha, R., & Pliukhin, O. (2013). New conditional symmetries and exact solutions of reaction-diffusion-convection equations with exponential nonlinearities. *Journal of Mathematical Analysis and Applications, 403*(1), 23-37. https://doi.org/10.1016/j.jmaa.2013.02.010

Dahan, E. (2025). Shaping Decentralized Collaboration in DAOs with a Requirements Engineering Framework. In: *Proceedings - 2025 IEEE 33rd International Requirements Engineering Conference Workshops, REW 2025* (pp. 383-394). Institute of Electrical and Electronics Engineers, Valencia, Spain. https://doi.org/10.1109/REW66121.2025.00056

Falah, J., Wedyan, M., Alfalah, S. F., Abu-Tarboush, M., Al-Jakheem, A., Al-Faraneh, M., Abuhammad, A., & Charissis, V. (2021). Identifying the characteristics of virtual reality gamification for complex educational topics. *Multimodal Technologies and Interaction, 5*(9), 53. https://doi.org/10.3390/mti5090053

Ferrer, J., Ringer, A., Saville, K., Parris, M. A., & Kashi, K. (2022). Students' motivation and engagement in higher education: The importance of attitude to online learning. *Higher Education, 83*(2), 317-338. https://doi.org/10.1007/s10734-020-00657-5

Ginters, E., & Revathy, J.C. (2021). Hidden and latent factors' influence on digital technology sustainability development. *Mathematics, 9*(21), 2801. https://doi.org/10.3390/math9212801

Ginters, E., Gutiérrez, J.M., & Mendívil, E.G. (2020). Mapping of Conceptual Framework for Augmented Reality Application in Logistics. In: *2020 61st International Scientific Conference on Information Technology and Management Science of Riga Technical University, ITMS 2020 - Proceedings, 1*, 9259302. https://doi.org/10.1109/ITMS51158.2020.9259302

Gong, Y. (2021). Application of virtual reality teaching method and artificial intelligence technology in digital media art creation. *Ecological Informatics, 63*(1), 101304. https://doi.org/10.1016/j.ecoinf.2021.101304

Hamad, A., & Jia, B. (2022). How virtual reality technology has changed our lives: An overview of the current and potential applications and limitations. *International Journal of Environmental Research and Public Health, 19*(18), 11278. https://doi.org/10.3390/ijerph191811278

Hamam, H., & Loucif, S. (2009). Web-based engine for program curriculum designers. *IEEE Transactions on Education, 52*(4), 563–572. https://doi.org/10.1109/TE.2008.2010988

Herrera-Pavo, M. Á. (2021). Collaborative learning for virtual higher education. *Learning, Culture and Social Interaction, 28*(766), 100437. https://doi.org/10.1016/j.lcsi.2020.100437

Hidayat, H., Sukmawarti, S., & Suwanto, S. (2021). The application of augmented reality in elementary school education. *Research, Society and Development, 10*(3), e14910312823. https://doi.org/10.33448/rsd-v10i3.12823

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

Imran, M., Almusharraf, N., Ahmed, S., & Mansoor, M. I. (2024). Personalization of e-learning: Future trends, opportunities, and challenges. *International Journal of Interactive Mobile Technologies, 18*(10), 4-18. https://doi.org/10.3991/ijim.v18i10.47053

Khaldi, A., Bouzidi, R., & Nader, F. (2023). Gamification of e-learning in higher education: A systematic literature review. *Smart Learning Environments, 10*(1), 10. https://doi.org/10.1186/s40561-023-00227-z

Khmil, N. A., Halytska-Didukh, T. V., & Tsyantsi, V. (2023). The use of virtual and augmented reality in Ukrainian education. *Academic Visions, 22*, 1-12. http://dx.doi.org/10.5281/zenodo.8251886

Kocharyan, A. B., Yachmenyk, M. M. & Garasymchuk, I. D. (2024). Integration of virtual reality and artificial intelligence into the educational process. *Science and Technology Today, 29*(1), 488-500. https://doi.org/10.52058/2786-6025-2024-1(29)-488-500

Kryshtanovych, M., Bilyk, V., Hanushchyn, S., Sheremet, I., & Vasylenko, K. (2021). Modelling the ways to increase the creativity of psychology students as a basic factor in professional development. *Creativity Studies, 14*(1), 34–50. https://doi.org/10.3846/cs.2021.12571

Kryvonos, O. M., Kryvonos, M. P., & Kovalchuk, M. V. (2024). The use of virtual reality in the educational process. *Scientific Innovations and Advanced Technologies, 1*(29), 735-748. https://doi.org/10.52058/2786-5274-2023-14(28)

Kudale, P., & Buktar, R. (2022). Investigation of the impact of augmented reality technology on interactive teaching learning process. *International Journal of Virtual and Personal Learning Environments, 12*(1), 1-16. http://doi.org/10.4018/IJVPLE.285594

Loucif, S., Al-Rajab, M., Salem, R., Hesham, A., Mahely, D., & Ajlouni, M.A. (2019). Learning human anatomy using ARA mobile application. *International Journal of Computing and Digital Systems, 8*(6), 589–596. https://doi.org/10.12785/ijcds/080606

Marks, B., & Thomas, J. (2022). Adoption of virtual reality technology in higher education: An evaluation of five teaching semesters in a purpose-designed laboratory. Education and Information *Technologies, 27*(1), 1287-1305. https://doi.org/10.1007/s10639-021-10653-6

Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). Virtual reality in education: A review of learning theories, approaches and methodologies for the last decade. *Electronics*, *12*(13), 2832. https://doi.org/10.3390/electronics12132832

Martynovych, N., Britchenko, I., Kolinets, L., & Popova, Y. (2024). On Sustainable Development under the Conditions of Human Capital Migration: A New Agenda for External and Internal Population Displacement. *Problemy Ekorozwoju, 19*(2), 23–34. https://doi.org/10.35784/preko.6230

Oleksandrivna, K.V., Fedchuk Oleksandr, V., & Pavlovich, M.V. (2023). Relationship between corporate culture and psychological safety of training and educational space for young female athletes. *Insight, 9*, 113–129. https://doi.org/10.32999/KSU2663-970X/2023-9-7

Paszkiewicz, A., Salach, M., Dymora, P., Bolanowski, M., Budzik, G., & Kubiak, P. (2021). Methodology of implementing virtual reality in education for industry 4.0. *Sustainability, 13*(9), 5049. https://doi.org/10.3390/su13095049

Petersen, G. B., Petkakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Computers & Education, 179*(1), 104429. https://doi.org/10.1016/j.compedu.2021.104429

Rasul, T., Nair, S., Kalendra, D., Robin, M., de Oliveira Santini, F., Ladeira, W. J., Sun, M., Day, I., Rather, R. A., & Heathcote, L. (2023). The role of ChatGPT in higher education: Benefits, challenges, and future research directions. *Journal of Applied Learning and Teaching, 6*(1), 41-56. https://doi.org/10.37074/jalt.2023.6.1.29

Research and Markets. (2023). *Global Virtual Reality (VR) in Education Market Report 2023: Increasing internet penetration drives growth*. Research and Markets.

Skrypka, H. V. (2023). The application of virtual reality technology in the conditions of distance and blended learning of a modern school. *Academic Notes. Series: Pedagogical Sciences, 211*, 201-208. https://doi.org/10.36550/2415-7988-2023-1-211-201-208

Smolinska, O., Koval, I., Pavliuk, M., & Shulha, D. (2024). Research of Assertiveness in Organization of the Time Perspective of Degree-Seeking Students in Higher Education. *Insight, 11*, 222–237. https://doi.org/10.32999/2663-970X/2024-11-12

Smutny, P. (2023). Learning with virtual reality: A market analysis of educational and training applications. *Interactive Learning Environments, 31*(10), 6133-6146. https://doi.org/10.1080/10494820.2022.2028856

Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., & Kourmpetis, M. (2021). The application of virtual reality in engineering education. *Applied Sciences, 11*(6), 2879. https://doi.org/10.3390/app11062879

Suman, S., Amini, A., Elson, B., & Reynolds, P. (2010). Design and development of virtual learning environment using open source virtual world technology. In N. Reynolds & M. Turcsányi-Szabó (Eds.), *Key Competencies in the Knowledge Society: IFIP TC 3 International Conference, KCKS 2010, Held as Part of WCC 2010, Brisbane, Australia, September 20-23, 2010. Proceedings* (pp. 379-388). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-15378-5_37

Tusher, H. M., Mallam, S., & Nazir, S. (2024). A systematic review of virtual reality features for skill training. *Technology, Knowledge and Learning, 29*(2), 843-878. https://doi.org/10.1007/s10758-023-09713-2

Vasylchak, S., Petrynyak, U., Loiak, L., Zagnybida, R., Khomiv, O., & Hnatenko, I. (2022). State regulation of employment in the labor market of territorial communities in the conditions of innovative development of entrepreneurship: aspects of management. *Journal of Hygienic Engineering and Design, 40*, 304–311.

Zajda, J. (2021). Constructivist learning theory and creating effective learning environments. In J. Zajda (Ed.), *Globalisation and Education Reforms: Creating Effective Learning Environments* (pp. 35-50). Cham: Springer. https://doi.org/10.1007/978-3-030-71575-5_3

Zhang, M., Ding, H., Naumceska, M., & Zhang, Y. (2022). Virtual reality technology as an educational and intervention tool for children with autism spectrum disorder: Current perspectives and future directions. *Behavioral Sciences, 12*(5), 138. https://doi.org/10.3390/bs12050138