Designing an immersive cloud-based educational environment for universities: a comprehensive approach

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Abstract

This paper presents a comprehensive approach to designing an immersive cloud-based educational environment (ICBEE) for universities. It defines the goals, structural components, functional modules, and actors of such an environment and provides a general metamodel reflecting its architecture. The paper suggests criteria for selection of immersive and cloud technologies, as well as guidelines for designing interactive learning content with augmented reality, virtual reality simulations and training applications. The proposed approach aims to create a methodological foundation for the development of ICBEEs as innovative ecosystems integrating advanced digital technologies and sound pedagogical practices to support active, personalized and practice-oriented learning.

Keywords

immersive learning, augmented reality, virtual reality, cloud technologies, educational environment, e-learning

1. Introduction

The ongoing digital transformation of higher education requires the development of innovative learning environments that leverage the potential of cutting-edge technologies to improve the quality and accessibility of educational services. Immersive learning approaches based on augmented reality (AR) and virtual reality (VR), coupled with the power and flexibility of cloud computing, open up new possibilities for designing interactive, engaging, and practice-oriented educational experiences [1].

An immersive cloud-based educational environment (ICBEE) can be defined as an integrated system that combines AR/VR tools, cloud services, learning management platforms, and various educational resources and activities to support learning, research, and management processes in a university setting [2, 3]. The design and implementation of such environments require a solid scientific and

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methodological foundation that takes into account the complex interplay of technological, pedagogical, and organizational factors.

The goal of this paper is to provide a comprehensive conceptual and methodological framework for designing ICBEEs at higher education institutions. The main objectives are:

- to define the goals, structural components, and main actors of ICBEE;
- to provide criteria for selection of AR/VR and cloud technologies for educational purposes;
- to suggest guidelines and principles for designing immersive learning content;
- to develop a general metamodel reflecting the architecture and key elements of ICBEE.

The rest of the paper is organized as follows. Section II provides a theoretical background on the concept and main components of ICBEE. Section III focuses on the principles and criteria for designing immersive learning content and selecting appropriate technologies. Section IV presents the results of the study in the form of a general metamodel of ICBEE and discusses its implications for the educational practice. Finally, Section V concludes the paper and outlines the directions for further research.

2. Theoretical background

2.1. The concept and goals of immersive cloud-based educational environment

The concept of immersive cloud-based educational environment (ICBEE) reflects the convergence of two major trends in modern education: the use of immersive technologies such as AR and VR to create more engaging and authentic learning experiences, and the adoption of cloud computing to enable flexible, scalable, and cost-effective delivery of educational services and resources [4].

The main goals of designing and implementing ICBEEs in higher education can be summarized as follows:

- to improve the quality of education by providing students with more interactive, personalized, and practice-oriented learning opportunities [5];
- to enhance the accessibility and flexibility of educational processes by leveraging the power of cloud platforms and services [6];
- to foster the development of students' and teachers' digital competencies required for effective learning and working in the modern technology-rich environment [7];
- to support innovative pedagogical approaches such as active learning, project-based learning, and remote collaboration [8];
- to enable data-driven decision-making and learning analytics based on the digital footprints of students' activities in the cloud-based environment [9].

Achieving these goals requires a holistic approach to the design of ICBEE that takes into account its complex structure and the interrelationships between its components.

2.2. Structural components of ICBEE

Based on the analysis of previous research [9], we can identify the following main structural components of an immersive cloud-based educational environment:

Spatial-semantic component, which includes the physical spaces of the university (classrooms, labs, collaboration zones) and their digital twins or virtual counterparts that can be accessed and interacted with using immersive technologies.

Technological component, which comprises the hardware and software infrastructure needed for the deployment and functioning of ICBEE, including:

- cloud platforms and services (IaaS, PaaS, SaaS) that host learning management systems (LMS), repositories, communication tools, and other applications [10];

- computing devices (servers, PCs, laptops) and specialized equipment for AR/VR experiences (headsets, controllers, trackers) [11];
- AR/VR development tools and frameworks (game engines, SDKs, libraries) used to create immersive learning content [12].

Content component, which encompasses the diverse types of digital learning resources and materials hosted in the cloud and accessible to students and teachers, such as e-books, video lectures, virtual labs, simulations, and assessments. This component also includes the data generated by the learning process itself (learning analytics, user activity logs, performance records) that can be used for personalization and improvement of educational services [13].

Communication component, which provides a set of tools and channels for synchronous and asynchronous learning interactions, collaboration, and experience sharing among the actors of the educational process. These may include video conferencing and webinar platforms, instant messaging and project management systems, social networks and forums.

Immersive component, which is specifically focused on AR/VR technologies and content that enable learners to interact with digital objects in a more natural and realistic way, creating a sense of presence and engagement. This component comprises:

- AR applications that overlay digital information onto the real world, e.g. by adding labels, 3D models, or instructions to physical objects or locations [14];
- VR simulations and virtual worlds that immerse the user in a fully digital environment, enabling them to practice skills, conduct experiments, and explore complex concepts in a safe and controlled way [15];
- 360-degree videos and images that provide an immersive view of real-world locations and phenomena, enhancing the learning experience and making it more memorable [16];
- haptic and motion tracking devices that enable more natural and intuitive interaction with virtual objects and environments [17].

These components form an integrated system in which the physical and digital spaces are blended, the learning process is mediated by a range of cloud-based tools and platforms, and the immersive technologies add an extra layer of interactivity and engagement. The design of ICBEE should ensure the seamless integration and interoperability of these components, as well as their alignment with the educational goals and pedagogical approaches.

2.3. Functional modules and services of ICBEE

The structural components of ICBEE described above are realized through a set of functional modules and services that support various aspects of the educational process. These include:

Learning management module (LMS), which serves as a central hub for organizing and delivering educational content, tracking student progress, and facilitating communication between teachers and students. Modern cloud-based LMS platforms such as Moodle, Canvas, or Blackboard provide a wide range of features and can be easily integrated with other tools and services [18].

Immersive learning content authoring and delivery module, which provides tools for creating, editing, and publishing AR/VR content such as 3D models, interactive simulations, and virtual tutorials. This module may include cloud-based platforms for 3D modeling and animation, AR/VR SDK and frameworks, as well as repositories for storing and sharing the created content.

Institutional repository module, which provides a centralized storage and access point for various types of digital learning resources and research outputs produced by the university staff and students. Cloud-based repository platforms such as DSpace or Eprints enable easy submission, description, and retrieval of materials, as well as their long-term preservation and accessibility.

Learning analytics and reporting module, which collects and processes data about students' learning activities, performance, and engagement in order to provide actionable insights for teachers, learners, and administrators. This module may include cloud-based tools for data mining, visualization, and dashboard creation, as well as predictive models for identifying students at risk and suggesting personalized interventions.

Communication and collaboration services, which enable synchronous and asynchronous interactions among the actors of the educational process, both within and beyond the classroom. These may include cloud-based tools for video conferencing, instant messaging, file sharing, and collaborative document editing, as well as social networking and project management platforms.

IT infrastructure management and security services, which ensure the reliable and secure operation of the cloud-based environment, including user authentication and authorization, data backup and recovery, performance monitoring, and cybersecurity measures.

The integration and interoperability of these modules and services is essential for creating a seamless and effective educational experience. The choice of specific tools and platforms should be based on their functionality, reliability, usability, and cost-effectiveness, as well as their compatibility with the existing IT infrastructure and the educational needs of the university.

3. Design of immersive learning content for ICBEE

3.1. Principles of designing immersive learning experiences

The effectiveness of immersive learning content in ICBEE largely depends on the proper application of key design principles that take into account the specificities of AR/VR technologies and their impact on the learning process. Based on the analysis of recent studies [2], we can identify the following main principles for designing immersive learning experiences:

1. **Interactivity and engagement**: the immersive content should enable learners to actively interact with digital objects and environments, manipulate them, and observe the consequences of their actions. This principle is essential for creating a sense of agency and involvement in the learning process.
2. **Realism and authenticity**: the virtual objects and environments should be designed to closely resemble their real-world counterparts in terms of appearance, behavior, and functionality. This principle is important for ensuring the transfer of knowledge and skills acquired in the virtual setting to real-life situations.
3. **Adaptability and personalization**: the immersive content should be flexible enough to accommodate different learning styles, preferences, and paces. It should provide learners with opportunities for customization, self-regulation, and choice, as well as adapt to their individual needs and performance.
4. **Multimodality and multisensory feedback**: the immersive learning experiences should engage multiple sensory channels (visual, auditory, haptic) and provide learners with rich and diverse feedback on their actions and progress. This principle is essential for enhancing the immersion, retention, and transfer of learning.
5. **Collaborative and social learning**: the immersive content should support various forms of collaboration and social interaction among learners, such as co-creation, peer feedback, and group problem-solving. This principle is important for fostering the development of soft skills, such as communication, teamwork, and leadership.
6. **Safety and ethics**: the immersive learning experiences should be designed with the physical and psychological safety of learners in mind. They should avoid any content or situations that may cause discomfort, distress, or harm, and adhere to the ethical standards and guidelines for the use of immersive technologies in education.

These principles should be applied in a balanced and context-specific way, taking into account the learning objectives, target audience, and available resources. The design process should involve a close collaboration between educators, subject matter experts, instructional designers, and AR/VR developers to ensure the alignment between the pedagogical goals and the technological solutions.

3.2. Guidelines for developing educational AR applications

Augmented reality (AR) is a powerful tool for enhancing the learning experience by overlaying digital information onto the real world and enabling learners to interact with it in a natural and intuitive way. Educational AR applications can be used for a wide range of purposes, such as visualizing complex concepts, providing contextual support, and gamifying the learning process [19]. To ensure the effectiveness and usability of AR applications in the context of ICBEE, the following guidelines should be followed:

- Use AR to provide contextually relevant information and guidance that enhances the understanding and retention of the learning material. For example, an AR application for a biology course may overlay labels, descriptions, and 3D models of organs onto a physical model of the human body.
- Leverage the unique affordances of AR, such as spatial anchoring, object recognition, and real-time tracking, to create immersive and interactive learning experiences. For example, an AR application for a history course may enable students to explore a virtual reconstruction of an ancient city by walking around a physical space and using their device as a "magic window".
- Use AR to scaffold and support the learning process by providing learners with timely feedback, hints, and prompts based on their actions and performance. For example, an AR application for a language learning course may use speech recognition to provide learners with real-time feedback on their pronunciation and suggest corrections.
- Design AR experiences that are accessible, inclusive, and user-friendly, taking into account the diverse needs and abilities of learners. This includes providing clear instructions, adjustable settings, and alternative modes of interaction (e.g., voice commands for learners with motor impairments).
- Integrate AR applications seamlessly into the overall learning flow and align them with the learning objectives, assessment strategies, and other digital tools used in the course. For example, an AR application for a chemistry lab may be linked to the corresponding sections of the e-textbook and the LMS gradebook.
- Ensure the technical stability, performance, and cross-platform compatibility of AR applications by using reliable development tools and frameworks (such as AR.js, ARCore, ARKit, or ARToolKit), optimizing the content for different devices and screen sizes, and providing clear instructions for installation and troubleshooting.
- Evaluate the effectiveness and usability of AR applications through user testing, learning analytics, and feedback from learners and educators. Use this data to iteratively improve the design and functionality of the applications and to inform future development efforts.

Some specific examples of educational AR applications that can be developed using these guidelines include:

- An AR-enhanced textbook for an engineering course that allows students to explore interactive 3D models of machines and mechanisms by pointing their device at specific pages or diagrams.
- A location-based AR game for an environmental science course that engages students in a simulated field study by placing virtual specimens, instruments, and data collection tasks in real-world settings.
- An AR-based language learning app that helps students practice vocabulary and grammar by overlaying translations, definitions, and examples onto real-world objects and scenes.

By following these guidelines and exploring the diverse possibilities of AR, educators and developers can create engaging and effective learning experiences that bridge the gap between the digital and physical worlds and support the development of 21st-century skills and competencies.

3.3. Approaches to designing VR simulations and training systems

Virtual reality (VR) simulations and training systems are among the most promising applications of immersive technologies in education, as they allow learners to practice skills, explore scenarios, and gain hands-on experience in a safe and controlled environment. In the context of ICBEE, VR simulations can be used for a wide range of purposes, such as medical training, scientific experiments, engineering design, and soft skills development [20]. To ensure the effectiveness and usability of VR simulations, the following approaches should be followed:

1. **Align the simulation design with the learning objectives and outcomes**: Start by clearly defining what skills, knowledge, and attitudes the learners should develop as a result of the VR experience, and use this as a basis for designing the content, interactions, and assessments.
2. **Create realistic and immersive environments that replicate the key aspects of the real-world setting**: Use high-quality 3D models, textures, and animations to create a visually compelling and believable environment that captures the relevant details and complexity of the simulated scenario.
3. **Provide learners with authentic and relevant tasks and challenges that require the application of the targeted skills and knowledge**: Design the simulation scenarios based on real-world problems, cases, or situations that learners are likely to encounter in their future professional or academic activities.
4. **Implement intuitive and natural interaction methods that mimic the real-world actions and behaviors**: Use VR controllers, haptic devices, or gesture recognition to enable learners to manipulate objects, navigate the environment, and perform tasks in a way that feels natural and realistic.
5. **Provide learners with adaptive feedback, guidance, and support based on their individual performance and needs**: Use intelligent tutoring systems, real-time analytics, and machine learning algorithms to track learners' actions, assess their progress, and provide personalized recommendations and scaffolding.
6. **Allow for collaborative and social learning experiences that foster teamwork, communication, and problem-solving skills**: Design multi-user VR simulations that enable learners to work together, share resources, and coordinate their actions towards a common goal, while providing tools for communication and awareness.
7. **Ensure the safety, comfort, and well-being of learners by following the best practices and guidelines for VR design and use**: This includes providing clear instructions and warnings, allowing for frequent breaks and adjustable settings, and avoiding any content or interactions that may cause motion sickness, eye strain, or psychological distress.
8. **Integrate VR simulations into the broader learning ecosystem by linking them with other digital tools, platforms, and resources**: For example, a VR medical simulation may be accompanied by an e-textbook, a discussion forum, and a performance dashboard that are all accessible through the LMS.
9. **Evaluate the effectiveness and impact of VR simulations through rigorous research and continuous improvement**: Use a combination of quantitative and qualitative methods, such as learning analytics, user surveys, and expert reviews, to assess the learning outcomes, user experience, and return on investment of VR simulations, and use this data to refine and optimize their design.

Some examples of VR simulations and training systems that can be developed using these approaches include:

- A VR laboratory for a chemistry course that allows students to conduct virtual experiments, manipulate 3D models of molecules, and observe chemical reactions in a safe and reproducible way.

- A VR clinical simulation for a nursing program that enables students to practice patient assessment, diagnosis, and treatment skills in a realistic hospital environment, with virtual patients that respond to their actions and decisions [21].
- A VR design studio for an architecture course that provides students with tools for creating, exploring, and presenting 3D models of buildings and landscapes, while collaborating with peers and experts from around the world.

By leveraging the immersive and interactive capabilities of VR, educators can create powerful learning experiences that bridge the gap between theory and practice, foster deep understanding and long-term retention, and prepare learners for the challenges and opportunities of the real world.

4. General metamodel of ICBEE

Based on the analysis of the structural components, functional modules, and design principles of immersive cloud-based educational environments presented in the previous sections, we propose a general metamodel of ICBEE that captures its key elements and their relationships (figure 1). The metamodel consists of four main layers:

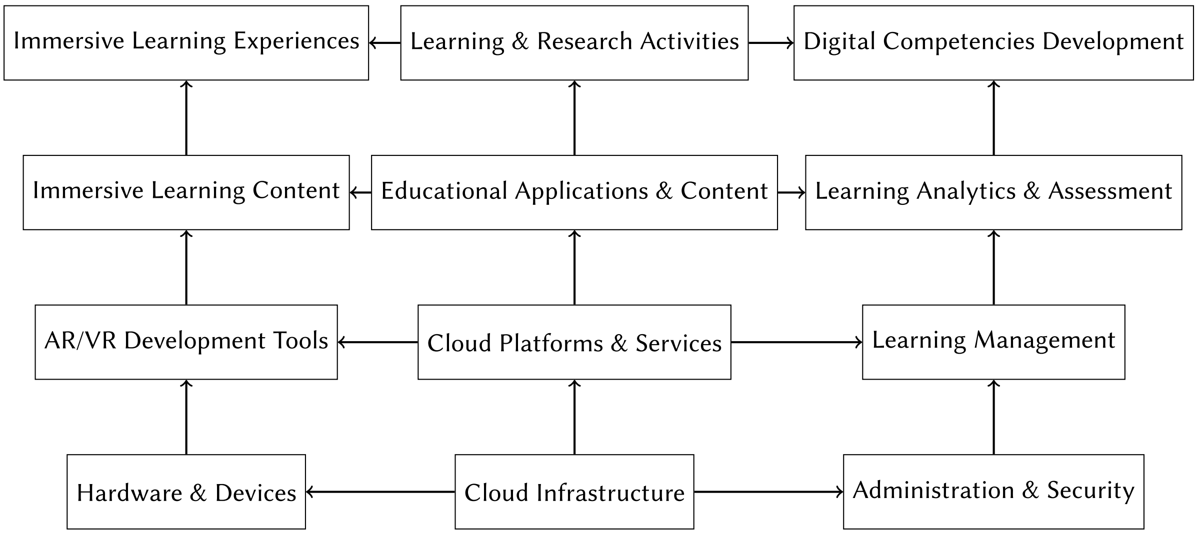

Figure 1: General metamodel of ICBEE.

1. The **Infrastructure** layer, which includes the physical and virtual computing resources, such as servers, storage, and networks, that support the operation of the cloud-based environment. This layer also encompasses the administration and security services that ensure the reliable, efficient, and safe functioning of the infrastructure.
2. The **Platforms and Services** layer, which includes the software components and tools that enable the development, deployment, and management of educational applications and content in the cloud. This layer consists of two sub-layers: (a) the general-purpose cloud platforms and services, such as learning management systems, collaboration tools, and data analytics engines; and (b) the specialized AR/VR development tools and frameworks, such as game engines, 3D modeling software, and device-specific SDKs.
3. The **Educational Content and Applications** layer, which includes the digital resources and software tools that are used directly by learners and educators in the learning process. This layer consists of two sub-layers: (a) the general educational content and applications, such as e-textbooks, video lectures, simulations, and assessments; and (b) the immersive learning content and applications, such as AR/VR simulations, 360-degree videos, and haptic interfaces.

4. The **Learning and Research Activities** layer, which includes the various forms of educational activities and experiences that are supported by the ICBEE, such as lectures, labs, projects, and research. This layer consists of two sub-layers: (a) the general learning and research activities, such as problem-based learning, collaborative learning, and scientific inquiry; and (b) the immersive learning experiences that leverage the unique affordances of AR/VR technologies, such as embodied learning, situational learning, and experiential learning.

The arrows in the metamodel represent the relationships and dependencies between the different layers and components. For example, the cloud infrastructure provides the necessary computing resources and services for the development and deployment of educational applications, while the AR/VR development tools enable the creation of immersive learning content that is used in the learning activities. The learning activities, in turn, generate data and feedback that can be analyzed using learning analytics tools to improve the quality and effectiveness of the educational content and applications.

The metamodel also highlights the cross-cutting aspects of ICBEE, such as the development of learners' digital competencies, which is supported by all layers of the environment, from the use of innovative hardware and software tools to the participation in authentic and meaningful learning activities. Another important cross-cutting aspect is the integration and interoperability of the different components and services, which is essential for creating a seamless and coherent learning experience.

The proposed metamodel provides a high-level conceptual framework for understanding the key components and relationships of immersive cloud-based educational environments. It can serve as a basis for the design, development, and evaluation of specific ICBEE implementations, as well as for the identification of research challenges and opportunities in this field. The metamodel can also be used as a communication tool for facilitating the dialogue and collaboration between the different stakeholders involved in the creation and use of ICBEE, such as educators, learners, researchers, IT professionals, and policymakers.

5. Conclusion

This paper presented a comprehensive approach to designing immersive cloud-based educational environments (ICBEEs) for higher education institutions. The proposed approach is based on a thorough analysis of the key components, functional modules, design principles, and development guidelines for ICBEEs, as well as on a review of relevant research and practice in the field.

The main contributions of the paper include: (a) a conceptual framework for understanding the goals, structure, and functions of ICBEEs; (b) a set of criteria and recommendations for selecting and integrating immersive and cloud technologies in educational settings; (c) a collection of design principles and guidelines for creating effective and engaging immersive learning content and experiences; and (d) a general metamodel that captures the key elements and relationships of ICBEEs and provides a high-level roadmap for their design and implementation.

The proposed approach and metamodel can serve as a foundation for further research and development in the field of immersive and cloud-based learning technologies. Some potential directions for future work include:

- Developing and evaluating specific ICBEE implementations for different educational contexts, domains, and levels, and studying their impact on learning outcomes, motivation, and satisfaction of learners and educators.
- Investigating the pedagogical, technological, and organizational factors that influence the adoption, use, and sustainability of ICBEEs in higher education institutions, and identifying the best practices and lessons learned from successful cases.
- Exploring the potential of emerging technologies, such as virtual and augmented reality, artificial intelligence, and learning analytics, to enhance the functionality and effectiveness of ICBEEs, and addressing the technical, ethical, and societal challenges associated with their use.

- Conducting comparative studies of different ICBEE designs and implementations, and developing benchmarks and standards for evaluating their quality, efficiency, and impact on learning and teaching.
- Examining the implications of ICBEEs for the roles, competencies, and professional development of educators, and designing training programs and support services that enable them to effectively integrate immersive and cloud-based technologies into their teaching practice.

Immersive cloud-based educational environments represent a promising and transformative approach to learning and teaching in higher education, one that leverages the power of advanced technologies to create engaging, personalized, and authentic learning experiences. The design and implementation of effective ICBEEs require a holistic and interdisciplinary approach that takes into account the complex interplay of technological, pedagogical, and organizational factors, and that is grounded in research-based principles and guidelines. The proposed metamodel and recommendations provide a starting point for this endeavor, but much work remains to be done to fully realize the potential of ICBEEs and to address the challenges and opportunities they present for the future of higher education.

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