Immersive Learning in Higher Education: Integrating Artificial Intelligence and Virtual Reality

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Abstract. In this paper we propose an innovative framework for improving immersive learning in robotics education that combines virtual reality (VR), extended reality (XR), and artificial intelligence (AI). The main focus is to apply robotics in areas such as manufacturing, logistics, and automation, and to explore how immersive tools can make the learning process more effective. Using VR headsets, learners have interactive simulations that reflect real situations, like checking a production line or managing robotic packaging. These practice-based experiences can help them to gain skills which are highly demanded in modern industry environments. Also, these simulations can show where mistakes in workflow might occur, but without the risks of real production. The aim of the proposed approach is to reduce the global shortage of skilled workers in robotics by offering training that is easier to access and closer to real-world practice. This method allows repetition of procedures at low cost, gives quick feedback, and helps students manage complex information more easily which differs from traditional teaching methods. The framework is flexible and can be tested within academic courses that follow educational standards. It also sets the stage for future work, including issues of ethics, technology, and law in robotics training, as well as the design of custom systems for more advanced learning.

Keywords: Immersive Learning, Virtual Reality, Extended Reality, Artificial Intelligence, Robotic Education.

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1 Introduction

Education in the field of robotics faces a number of challenges in the era of digital transformation. On the one hand, there is a lack of qualified labor in the production, logistics and automation sectors, while on the other hand, the demand for employees with knowledge in robotics, automation and mechatronics is constantly increasing. Despite the growing global skills gap in robotics and manufacturing, it is clear that traditional education methods are failing to develop the necessary practical and digital skills.

New trends in industry show that robotics is one of the most in-demand skills today. Research conducted by Deloitte and the Manufacturing Institute in 2021 predicts that by 2030, 2.1 million manufacturing jobs will remain unfilled in the United States [1]. The World Economic Forum predicts a shortage of over 7 million skilled workers in manufacturing by 2030. At the same time, only 30% of the workers on the production line have the necessary skills in accordance with the new digitization trends, and the demand for robotics is the most pronounced [1].

It can be concluded that the growing gap between what the industry requires and the skills in the field of technology possessed by experts requires a change in educational learning models. In this context, technologies of virtual reality (VR), augmented reality (XR) in integration with artificial intelligence (AI) provide new opportunities for learning through interaction and simulations in realistic but controlled conditions. Immersive learning enables students to face complex industrial scenarios (e.g. control of a production line or robotic packaging) in realistic conditions. In this way, cognitive assimilation of knowledge is improved and operational risks are reduced.

The combination of VR, XR, and AI can significantly transform education, providing scalable, efficient, and ethically sound learning models to advance education in the domains of robotics and industrial automation, potentially closing the existing gap between academic learning and industry demands.

This paper is organized as follows: In Section 1, we provide an introduction that outlines the current state of robotics and the challenges of integrating XR and AI technologies, with a particular emphasis on the shortage of industrial skills; Section 2 reviews relevant research and presents the proposed framework; Section 3 elaborates on the integration of XR solutions; Section 4 discusses the methodology for validation and implementation in academic courses; Section 5 highlights the expected results in terms of enhancing student skills, fostering interactive learning, and reducing operational risks; finally, the conclusion summarizes the contributions and outlines future development perspectives.

2 Related work

It is undeniable that new technological trends have imposed new requirements in the organization and management of teaching and learning. Contemporary technological achievements and the application of AI tools emphasize the need to identify and analyze issues related to their implementation in the education sector.

The influence of AI in education has increased significantly and the academic sphere is becoming more efficient and personalized, but also global, contextually intensive and asynchronous [2]. A number of authors point out that the competitiveness of higher education institutions is conditioned by increasing the efficiency of learning methods, i.e. the application of AI tools in education [[3], [4], [5]]. Kee & Zhang [6] and Neroni et al. [7] state that the implementation of IVR can increase student motivation and engagement, while simultaneously reporting difficulties in student concentration due to technology and the social environment [8]. Sung et al. [9] confirm the improvement of students' attitude and greater enjoyment of learning compared to classic video materials, while Pande et al. [10] point out that IVR promotes long-term knowledge retention and greater interest compared to video content, although perceived learning benefits diminish over time. On the other hand, Al-Azawei et al. [11] concluded that no significant differences were found in performance or ease of use compared to interactive e-testing in learning management systems (e.g. Moodle).

There is a possibility of the appearance of positive and negative emotions during the application of IVR, where the intensity of emotions depends on the design of the IVR environment and the students' self-confidence [12]. Positive effects of IVR learning can occur in the field of mechanical and electrical engineering [13], in learning foreign languages compared to mobile applications [14] and for improving oral presentation skills during public presentations [15].

Perez & Keleş [16] propose a model for the future development of education based on VR technology, which by encouraging deeper connections between cognitive processes and physical activities improves student learning outcomes. A new framework for Virtual Laboratory Environments (VLEs), focuses on learning through bodily experience, offering students the opportunity to physically interact with virtual samples and machines from the fields of mechanical and materials engineering. Compared to traditional (non-corporeal VR methods), research results have shown significant improvements in students' understanding and retention of knowledge, along with better test scores. The authors conclude that immersive VR environments can significantly enhance the learning experience for engineering students through hands-on and interactive experiences.

Stracke et al. [17] with a systematic analysis of scientific works on the application of immersive virtual reality in higher education, conclude on the one hand that a large number of studies highlight the positive impact of IVR on the degree of student engagement, encouraging interactive and research activities, supporting specific learning processes, increasing the enjoyment of learning and complete immersion in IVR environments. However, the authors also state that the implementation of IVR does not automatically lead to an improvement in the learning process, as numerous studies show no significant differences in educational outcomes between IVR and traditional learning methods, and recommend a careful analysis of the specific conditions of IVR application (physical side effects, the need to accept technology and individual differences among students), as well as its meaningful integration into the curriculum.

Creating highly engaging and personalized learning environments by integrating immersive technology and AI has the potential to transform traditional education systems. Bekteshi [18] states in his work that the application of immersive technologies (VR, AR, Mixed Reality - MR) and AI can significantly improve educational outcomes by: facilitating conceptual understanding through experiential and interactive learning, increasing the rate of knowledge retention through engaging, gamified and immersive educational scenarios, by providing safe and controlled simulations. Immersive technologies increase student interest by making teaching interactive and visually striking, while AI personalizes environments by adapting content and pace to individual student needs while providing real-time feedback [18]. The integration of immersive technologies (experiential context necessary for deeper learning) and AI (enhances interactivity and adaptability of VR/AR environments) represents a powerful combination for improving education [18].

Compared to previous research, this paper proposes a comprehensive and scalable framework that integrates VR, XR, and AI technologies with the aim of advancing education in the field of robotics. Unlike existing approaches, the proposed framework provides practice-oriented, transferable, and ethically grounded training aligned with contemporary educational standards.

3 Proposed framework

The proposed framework for immersive learning in higher education consists of the integration of AI and VR and is based on the previously developed XR4Human-SERVE 5.0 approach [19]. This project demonstrated the feasibility of neuroergonomics – the interaction of humans and other parts of the system and the work environment itself – with an XR-enabled assembly workstation, which was validated in the context of an SME with multimodal interfaces and cognitive assessment integrated into a single XR headset. XR4Human-SERVE 5.0, Horizon Europe established a comprehensive and integrated immersive learning environment that leveraged the synergistic potential of VR, XR and AI to enhance robotics education. Our current framework aims to overcome the shortcomings of traditional robotics curricula, which are effective in providing theoretical knowledge and limited laboratory practice. Practical teaching in higher education institutions, in most cases, cannot provide students with a certain amount of practical engagement, often due to the unavailability and affordability of certain expensive equipment. For these reasons, and the very requirements of the industries and their realities, a new framework is needed to implement practical training for students. Our framework relies on constructivist learning theories, which refer to the field of active learning and the discovery of cause-and-effect relationships that are part of the study, as well as contextualized interaction in the acquisition of knowledge and the development of skills [20].

The basis of our framework consists of three interdependent modules that address critical issues in current robotics education:

- Immersive simulation environments;
- Adaptive learning systems powered by AI;
- Assessment and feedback mechanisms.

Immersive simulation environments, as the first module, consist of high-quality XR simulations that replicate complex industrial scenarios such as robotic assembly lines, warehouse logistics operations, and automated inspection in quality control. Unlike traditional university labs, specially created virtual environments offer scalability and repeatability. Students can experiment with and operate simulated robotic machines (most often replicas of robotic industrial arms) without the risk of equipment damage or safety hazards. Such an approach is consistent with previous research showing that immersive robotics-focused learning games and VR platforms, such as Robotics Academy and IL-PRO, successfully provide safe, repeatable, and industrially relevant training environments [21]. The design of the simulation is based on the fundamental principles of cognition, which state that learning is most effective when cognition is based on sensorimotor and hands-on experiences. Our research is also consistent with studies showing that active physical engagement improves conceptual understanding, as students who physically interacted with objects while actively participating in tasks outperformed those who merely observed [22]. Thus, by engaging students in physically and cognitively rich contexts, the first module of our framework demonstrates that learning through practice is more effective than traditional learning. Furthermore, the proposed framework for immersive learning bridges the gap between abstract robotics concepts on the one hand and applied industrial practice on the other.

Our second module uses adaptive AI systems to enable personalization of the educational model and adaptability to a large group of students. Machine learning algorithms analyze patterns obtained in interactions with students. The module's algorithms track success and achievements in solving performance tasks such as: response time, error rate and navigation strategies and, based on the results, dynamically adjust the difficulty of tasks, introduce task difficulty scaling mechanisms or offer targeted micro-interventions. Thanks to the system's adaptability and constant feedback, students receive a differentiated educational experience aligned with their prior knowledge, learning pace and cognitive preferences. In addition to personalization - adjusting the difficulty level to each student individually, we expect AI to function as an intelligent mentor, a guide, offering contextual advice, guiding reflective thinking and simulating collaborative problem solving through natural language dialogue, especially in robotics education, as shown by Kal et al. [23]. ARtonomous is an example of a successfully implemented project that integrates adaptive AI in robotics education. ARtonomous allows high school students to train virtual robots using reinforcement learning within an adaptive simulation environment - students dynamically engage with changing task difficulty based on real-time performance [24].

Assessment and feedback mechanisms, as the third module, provide comprehensive, continuous and formative assessment of results. Assessment mechanisms integrate multimodal assessment strategies that capture behavioral data, interaction logs, and task results for each student. Dashboards visualize student progress in real time, and the results are available to both students and instructors. The capabilities of an automated feedback mechanism can foster self-regulated learning, i.e., the student has the ability to manage and continuously regulate his or her own learning process. Yang et al. [25] found that frequent testing combined with feedback significantly enhances long-term memory in students. Immersive technologies emphasize the importance of multimodal feedback such as visual feedback, tactile feedback, and adjustable sensory channels, as well as the importance of personalizing educational materials to support inclusive education and meet the diverse needs of students [26]. The third framework aims to digitize existing robotics curricula, and to transform pedagogical practice using immersive, adaptive, and ethically grounded educational experiences.

4 Proposed development and integration of XR platform

The development of the XR platform represents a practical implementation of the proposed framework Immersive Learning in Higher Education: Integrating AI and VR. The development itself requires a balance between technical reliability, pedagogical goals, and user-centered approach and design. This platform will be the backbone of immersive robotics education because it supports both individual and team learning approaches, as suggested in the literature [27].

To develop the XR platform, we require:

- Hardware devices;
- Software architecture;
- Integration of artificial intelligence.

Hardware devices are: VR headsets that provide a sense of immersion in the VR space thanks to high-resolution displays; haptic gloves and feedback devices that allow tactile interaction with objects in the virtual environment; and motion tracking systems, which are often integrated with other devices, VR headsets, vests, and gloves. There are also more advanced systems that can further enrich our stay in the VR world, such as integration with exoskeletons or wearable sensors that can capture additional feedback. Studies highlight the key role of VR/AR integrated with haptics in enabling multisensory, embodied learning for STEM contexts [28], while recent work in engineering education highlights the frameworks of haptic interaction for interactive learning [29].

A software platform built on engines such as Unity and Unreal Engine that have model design capabilities, advanced physics simulation capabilities, and real-time rendering capabilities. The modular design allows developers to recombine existing parts of the system, without disrupting the overall system, and create new scenarios for robotics training. The cloud, which stores data, provides the ability for multiple users to access the platform simultaneously and enables teamwork on common tasks. The integration of artificial intelligence and learning models that allow for dynamic adjustment of task complexity based on student performance in real time enhances the platform's functionality. We have reinforcement learning (which involves training machine learning models using computer programs) supporting the generation of personalized scenarios. New scenarios allow students to encounter new variations of problems that improve the transfer of knowledge to real-world robotics practice. Natural language processing (NLP), which combines computational linguistics, predictive artificial intelligence, and deep learning models to process human language, and the modules function as a virtual assistant with whom we can talk, guide us through the training process, and provide us with answers to the questions we ask. By successfully integrating artificial intelligence and the software platform, we ensure the compatibility of task difficulty and a personalized approach to students.

The design of the platform should follow the principles of human-computer interaction (HCI) focused on the ease of use of the proposed frameworks for immersive learning. The platform should have intuitive interfaces that are easy to understand, visual cues that have universal meaning, and progressive scaling of tasks. The platform should have the ability to adjust visual elements, such as text size, accessible audio descriptions, i.e. tutorials for solving tasks, and be compatible with assistive devices. The platform itself must meet ethical principles and foster inclusiveness among diverse student populations [[27], [30]].

The platform design uses recognized standards such as SCORM, xAPI, and LTI for compatibility with Learning Management System (LMS) systems, and facilitates integration into existing curricula and allows for tracking student achievement across platforms and institutions. Interoperability is supported by recent initiatives in XR-based robotics education that emphasize the importance of interoperability and collaborative learning in industrial contexts [31].

The development of the XR platform also follows a design-based research (DBR) methodology. The iterative approach is a circular model for developing a platform that involves iterative cycles of prototyping, testing, and refinement, through several iterations: in the first phase, a prototype is tested, then feedback is used to improve that prototype – this process is used until we are satisfied with the functionality of the platform itself. Early prototypes are tested with a small group of students and educators, then the design is modified and pedagogical fit and technical robustness are taken into account. Later iterations, nearing the completion of the platform, involve larger-scale testing with more diverse cohorts to improve scalability and reliability. DBR is established as a methodology for developing technologically advanced learning environments, especially for balancing theory with iterative design in authentic contexts [32]. The XR immersive learning platform aims to be a high-quality, simple and pedagogically effective network that connects theoretical robotics education with current industrial needs [28].

5 Validation and deployment of platform at academic courses

Validation and implementation of the platform represent a phase of transition from the conceptual framework of platform development, presented in the previous chapters, to practical application in the educational process in higher education. This phase requires rigorous empirical, systematic, testing, systematic integration into curricula and programs, and long-term sustainability planning [33].

Validation begins with pilot projects conducted in selected robotics courses at the Metropolitan University of Belgrade, such as operations research, machine learning, artificial intelligence, and virtual/augmented reality (VR/AR) in video games. These pilot projects will represent mixed-method research designs, combining quantitative and qualitative approaches to obtain a holistic picture of the effectiveness of the platform. Experimental settings will include control and experimental groups: the control group engages in conventional, traditional, teaching, while the experimental group uses the XR platform.

The experimental approach will allow for comparative analysis of outcomes such as skill acquisition, conceptual understanding, and motivation [33]. Quantitative data collected and processed by the platform includes the time it took the student to complete the tasks, the number of errors they made, and the retention time for each individual task. Thanks to the data obtained, we will have objective evidence of the development of skills and the percentage of students' task-solving efficiency. In addition to quantitative data, qualitative data will address students' perceptions of engagement during practical work on tasks, the degree of motivation, and the ease, i.e. difficulty, of using the platform. Quantitative and qualitative data will provide triangulated evidence of the educational impact of the platform, as shown in the literature [34].

Feedback collected during the platform development cycle from the initial pilot project enables further, iterative, refinement of the technical and pedagogical aspects of the platform. For example, if learners have difficulty navigating complex interfaces and report a problem, then usability adjustments will be made, i.e. interface redesign. Similarly, performance data can reveal where AI-driven personalization requires modification of task difficulty. Iterative feedback was intended to ensure that the platform evolved in response to real-world use and the needs of different industries [28]. Implementation requires extensive engagement of academic staff who should be trained in the technical functioning of the XR platform and its pedagogical integration. Organized workshops and professional development sessions should be designed to adapt specific teaching subjects to immersive learning. For example, educators will be guided on combining XR activities with theoretical lectures, assignments and lab exercises, as outlined in the supporting literature [27].

The implementation should take into account ethical principles and legal issues, i.e. the security of the data entered by the student should be ensured. Data governance policies are established to govern the collection, storage and analysis of student data, ensuring compliance with data protection regulations such as the GDPR [35]. Students should follow informed consent protocols that are implemented to guarantee transparency and their autonomy. Accessibility standards are built into the implementation to ensure the inclusiveness of all students - that no student is disadvantaged due to disability or resource constraints. The goal of the implementation is to create a sustainable model for immersive learning in the workplace, which includes establishing maintenance protocols, providing ongoing technical support, and updating technical maintenance. Feedback loops allow for continuous data collection from instructors and students to drive iterative improvements to the platform. The platform is intended as a tool for robotics education, but also as a scalable model that can be adapted to other technical disciplines, such as mechanical engineering, mechatronics, or even healthcare training [28]. The XR platform is intended to become an integral and sustainable part of academic programs through rigorous validation and careful implementation of all components. The long-term contribution of the learning platform in higher education is reflected in the possibilities of a new form of immersive, adaptive and ethically responsible education that prepares students for the complexities of the Fifth Industrial Revolution.

6 Expected results

Significant industrial, operational and pedagogical outcomes are expected to be generated by implementing the suggested framework for combining AI and XR, which directly addresses the observed skills gap in industrial automation and robotics. Students are primarily expected to significantly improve their robotic systems operation, programming and troubleshooting skills. By providing a variety of contextual experiences that are usually unavailable in physical labs due to resource limitations, the realistic simulations in this mastery learning environment enable repeated and intentional implementation of complex activities, which has been proven to significantly improve the development of performance and diagnostic skills [36]. AI-driven personalization further enhances this by offering adaptable challenge levels and tailored feedback, thereby targeting each learner's unique speed of skill development and encouraging higher cognitive engagement and self-regulated learning [[37], [38]].

This framework leverages scalable XR technologies in order to provide affordable access to industrial simulations of sophisticated robotic factories that would otherwise be too expensive or logistically challenging to establish in a classroom [39]. By making high-end practical training a crucial part of robotics education, this experience allows students from various institutional backgrounds to achieve a shared standard of practical competency, thereby helping to close the worldwide industrial skills gap. Long-term sustainability and continuous upkeeping with constantly developing technologies and industry standards are ensured by the platform's design for modular content expansion and reuse.

Moreover, it is expected that the framework's ability to simulate a realistic industrial setting will enhance systemic thinking ability and strong situational awareness of graduates entering the workforce. Industrial environments' physical characteristics and dynamic operating challenges, such as production bottlenecks, system malfunctions and time limitations, are intended to be replicated by the highly precise simulations. Since learners must combine past knowledge, strategic reasoning and sensory data in order to solve problems, which are crucial indicators of proficient skills in complex situations, this exposure is expected to enhance decision-making and cognitive load management under pressure [[40], [41]]. Students are additionally trained in dispersed cognition and team coordination as crucial industry skills by the multi-user collaborative functionality [42]. A highly engaging learning environment that increases student enjoyment and motivation, leading to better learning outcomes, is created by integrating multimodal interaction through visual, auditory and tactile feedback [[9], [17]].

Lastly, the most significant outcome is the substantial reduction of operational risk. The framework acts as a vital risk-free testing ground where catastrophic failures and safety protocols can be experienced without real-world repercussions by enabling students to make mistakes and experience failure situations in a virtual setting. This firsthand experience of failure states and safety procedures is essential for creating a deeply rooted safety culture and procedural memory, thereby lowering the likelihood of accidents and expensive mistakes in actual industrial operations [43]. The AI system's objective performance data collection makes it possible to precisely identify deficient skills before they manifest in dangerous situations, ensuring that graduates join the workforce skilled, as well as risk-aware and safety-conscious [44]. By giving learners ongoing feedback and ensuring that their practical skills are firmly established before being applied in the real-world industrial setting, the AI-powered assessment module contributes to developing a future workforce that is more competent and safety-conscious.

7 Conclusion

This paper proposed a framework that combines VR, XR and AI in order to advance robotics education. With this approach and use of immersive simulations, students can practice in realistic and safe environments. In this way they can build various technical skills, and prepare for the demands of modern industry. The framework also helps in reducing the global skills gap because students have access to training that is practical, low-cost, and closer to real-world scenarios. The proposed learning process uses adaptive AI and constant interactions with students so that learning becomes more flexible, personalized, and engaging. Overall, this approach creates a strong foundation for connecting academic education with industrial needs.

In the future, the proposed framework should be tested in real academic courses to measure the impact on student skills and motivation. Also, there is a need for feedback from learners that gained knowledge with use of immersive simulations and used it in real industry environments. It will also be important to explore in more detail ethical and legal aspects, such as data privacy and accessibility for all learners. Further development of the proposed approach can include new robotics scenarios and integration with other fields like healthcare or mechanical engineering. By continuing this research, the framework can grow into a widely used tool for practical and safe training in many areas of education.

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