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Robotics in higher education and its impact on digital learning

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In recent years, robotics has transformed various industrial processes but has also influenced teaching methodologies. Although there are literature reviews on its application in professional training, many are outdated or lack a current focus on its impact in higher education. Addressing this gap, the present mini review examines the impact, challenges, and opportunities of this technology in the university setting. To this end, a search was conducted in the PubMed, Scopus, IEEE Xplore, APA PsycNet, and Web of Science databases, selecting 11 studies that addressed diverse applications of robotics, including educational robotics, robotic telepresence, human-robot interaction, and artificial intelligence applications. Their effects on teaching, the factors influencing their adoption, and the strategies used to optimize their implementation were analyzed. The findings show that educational robotics enhances student motivation and engagement, with prediction models reaching an accuracy of 98.78% in assessing academic engagement. Additionally, robotic telepresence emerges as an effective alternative for hybrid education, and social robots and AI-based tutors demonstrated their potential to personalize learning. However, methodological and structural challenges persist, such as the need to develop more accurate evaluation metrics and ensure accessibility and educational equity. Future research should focus on improving these aspects, enabling more efficient integration to enhance teaching processes. This study was registered in the Open Science Framework under the code: 10.17605/OSF.IO/KHDTU.

KEYWORDS

educational robotics, higher education, personalized learning, artificial intelligence, stem

1 Introduction

Robotics has significantly evolved over the past decades, transitioning from a discipline exclusive to industry to a technology with applications across multiple sectors (Xiao et al., 2022). In education, its integration at various educational levels has enabled the development of both technical and cognitive skills among students (Varela-Aldás et al., 2020; Jalinus et al., 2021; Almulla and Al-Rahmi, 2023). Robotics not only facilitates the teaching of programming and engineering but also promotes critical thinking and problem-solving, key competencies in the digital age (Ortega-Ruipérez and Lázaro Alcalde, 2023). In higher education, educational robotics goes beyond traditional teaching methodologies and has become a foundational tool for training professionals in technology, engineering, and applied sciences (Roldán-Álvarez et al., 2024).

The implementation of robotics allows students to apply theoretical knowledge in practical environments, strengthening their understanding of algorithms, mechanical design, automation, and systems control (Shastri, 2025). Furthermore, this approach fosters creativity and innovation by encouraging the development of projects that address real-world problems. Its impact extends beyond the technical realm, as it also promotes the adoption of modern teaching strategies and supports experiential learning aligned with labor market demands. In this context, social robots and game-based tools have proven effective for developing digital skills from basic education through to university (Leoste et al., 2021b). The incorporation of game-based learning combined with robotics not only motivates programming education but also enhances computational thinking and problem-solving skills (Brown and Tsugawa, 2024).

Previous studies have analyzed the impact of educational robotics across various educational levels, identifying both its benefits and the limitations associated with its implementation. In their review, Atman Uslu et al. (2023) conducted a mapping of research on educational robotics, analyzing 93 studies indexed in the Social Sciences Citation Index (SSCI). Their work revealed that many studies lack solid theoretical frameworks and that experimental research in educational robotics remains limited in terms of empirical validation. Similarly, Tselegkaridis and Sapounidis (2021) conducted a review focused on educational robotics simulators, highlighting their potential to reduce costs and expand access to learning experiences without physical hardware, though they also noted a lack of studies evaluating their effectiveness in higher education settings.

Other reviews have explored the use of robots in education, though focusing on other academic levels. Zhang et al. (2021) described the impact of robots on computational thinking and STEM (Science, Technology, Engineering, and Mathematics) attitudes among K-12 students, concluding that effects vary depending on the population and the duration of the intervention. Likewise, Woo et al. (2021) reviewed studies on social robots in the classroom, identifying challenges in autonomy and personalization of interaction with students. Although these studies help to understand the role of robotics in learning, they do not specifically address its application in higher education or its relevance to the development of advanced technical skills.

In this context, the present review focuses on the role of educational robotics in developing increasingly in-demand digital and technical competencies in professional training. Its applications in teaching are analyzed, identifying effective strategies and challenges in implementation. These findings can serve as a foundation for future research and the development of strategies that optimize teaching processes.

2 Methods

This study explores the implementation of robotics in higher education as a tool for developing competencies in information technologies. A qualitative, non-experimental approach was employed, drawing on a narrative review of recent academic literature. The goal is to analyze how educational robotics contributes to the development of technical and digital skills in university-level students.

2.1 Literature exploration

To gather relevant material, a targeted search was conducted across five reputable academic databases: PubMed, Scopus, IEEE Xplore, APA PsycNet, and Web of Science. The selection focused on studies published within the past 5 years to ensure topical relevance. Keywords such as "robotic", "higher education", "digital skills", "technical skills", "skill development", "competency", "educational robotics", "hands-on learning", and "simulation" were used in various combinations with Boolean operators to identify pertinent sources.

2.2 Selection scope

Priority was given to peer-reviewed articles and conference papers published in English between 2020 and 2024 that address the use of robotics in promoting digital and technical skill development in higher education settings. Studies were selected based on their relevance to the topic rather than through a formal systematic filtering process.

2.3 Exclusion considerations

Studies focusing on primary or secondary education, industrial or healthcare applications of robotics, or those lacking empirical or pedagogical grounding were excluded from the core analysis. Access limitations were also considered during the selection.

2.4 Data overview

The selected literature was organized and reviewed thematically. Relevant details such as authorship, publication year, applied technologies, and educational context were noted. Particular attention was paid to the key findings and educational strategies reported in the literature. Reference management was facilitated through Mendeley to maintain a coherent database of sources.

3 Results

The literature reviewed shows a growing interest in the application of robotics in higher education, particularly as a tool for supporting the development of technical and digital competencies. Through an exploratory review of recent publications, a selection of relevant studies was identified that showcase various implementations and technologies within university settings.

3.1 Technologies used

The description of the reviewed studies is presented in Table 1, where various technologies applied in higher education were identified. Educational robotics ($n = 4$) was the most frequently used, highlighted for its ability to support programming instruction and the development of STEM skills. Human-robot interaction ($n = 1$) was also analyzed, proving to be an effective tool for assessing student engagement through prediction models based on supervised learning. Robotic telepresence ($n = 2$) was presented as a solution to enhance interaction in hybrid learning environments and strengthen remote communication in higher education. Other emerging technologies included software robots and artificial intelligence ($n = 1$), as well as social robotic tutors ($n = 1$), which were designed to tailor teaching to individual student needs.

3.2 Impact on higher education

Findings showed that robotics in higher education had a significant impact on various aspects of learning. Prediction models involving human-robot interaction demonstrated high accuracy, indicating that these tools can enhance motivation and engagement in academic activities. Additionally, the efficiency of teaching STEM and programming ($n = 4$) confirmed that integrating educational robotics and games facilitated the understanding of complex concepts in computer programming and computational thinking. Moreover, the development of transversal skills through academic projects and active methodologies revealed that robotics influenced not only technical learning but also teamwork and problem-solving in practical contexts.

4 Discussion

The integration of educational robotics in higher education has represented a transformation in teaching methodologies and has also promoted the development of digital skills in the current professional landscape (Muñoz-Repiso and Caballero-González, 2019).

4.1 Emerging scenarios in digital education

The reviewed studies showed that educational robotics helped enhance student participation and engagement, especially in technical disciplines. This impact can be attributed to the interactive nature of robotics, which facilitates experimentation and active learning, key elements for the development of digital and technological competencies. Prediction models in human-robot interaction reached accuracies of 98.78%, suggesting their usefulness in assessing student motivation and performance (Cui et al., 2022). Additionally, robotic telepresence has proven to be a relevant tool in hybrid learning environments, enabling educational continuity in scenarios with limited face-to-face interaction. Its implementation allowed students to maintain more fluid connections with instructors and peers, reinforcing accessibility and equity in higher education (Azukas and Francois, 2024).

Project-based learning and collaborative approaches complement the integration of educational robotics, as they promote the practical application of knowledge and the development of problem-solving skills (González-Fernández et al., 2021). However, resource availability remains a challenge for many institutions, prompting the use of low-cost robots as a strategy to democratize access to these technologies (Abidin et al., 2021). Furthermore, the use of robotics in socially impactful projects has extended its applications beyond the classroom. For example, at Tecnológico de Monterrey, the integration of NAO humanoid robots helped address issues related to educational inclusion and accessibility, aligning with the Sustainable Development Goals (Lopez-Caudana et al., 2024).

Beyond its impact on technical education, educational robotics has driven the transformation of learning environments, enabling the incorporation of multidisciplinary approaches that combine knowledge in engineering, programming, pedagogy, and social sciences. In this regard, technologies such as Mobile Robotic Telepresence (MRT) have demonstrated their potential to enhance interaction in hybrid classes, ensuring a more immersive learning experience (Azukas and Francois, 2024). As these initiatives continue to develop, robotics not only optimizes educational processes but also fosters the creation of sustainable solutions applicable across various sectors.

4.2 Challenges in the integration of robotics

Despite its positive impact, the adoption of this technology faces several challenges that hinder widespread implementation. One of the main obstacles is the lack of technological infrastructure, which makes it difficult to integrate advanced systems into institutions with limited resources (Castro et al., 2022). This limitation prevents many students from accessing robotics-based learning experiences, creating a gap in educational equity. Moreover, the effective implementation of these technologies heavily relies on teacher training. While initiatives such as intervention seminars for future educators have shown improvements in their digital competencies and their ability to teach computational thinking (Fehrmann, 2024), the lack of specific training in the pedagogical use of robotics remains a barrier to effective classroom application (Denis and Hubert, 2001).

Another challenge identified was the need to ensure inclusion in educational environments mediated by robotics. Although these technologies have shown potential to enhance accessibility, the lack of specific strategies for students with special needs limited their reach. Incorporating more inclusive approaches in the design of educational robots could enhance the learning experience for a broader range of students (Louie et al., 2022).

From a methodological standpoint, advances in educational robotics have raised new questions about the assessment of learning. Although progress has been made in using predictive models and data analysis in education, challenges persist in measuring competencies acquired in robotics-mediated environments. The need to develop more accurate metrics that reflect the impact of these technologies on learning remains an evolving area of research.

TABLE 1 Characteristics of the studies included in the review.

Reference	Technology/method	Focus	Key findings
Brown and Tsugawa (2024)	Games and robotics	Computer programming instruction	The use of games and robotics to teach STEM subjects enhances learning and engagement, particularly in secondary-level computer programming.
Fehrmann (2024)	Educational robotics	Promotion of computational thinking	Investigates the use of robotics in higher education to promote computational thinking among future elementary school teachers, including intervention seminars aimed at improving their digital competencies.
Azukas and Francois (2024)	Mobile robotic telepresence	Post-pandemic education	Discusses the use of mobile robotic telepresence to enhance interaction in hybrid classes and strengthen the connection between instructors and students, enabling more dynamic and inclusive learning experiences.
Lopez-Caudana et al. (2024)	Robotics for social support	Academic projects	Focuses on academic projects that use robotics to provide social support, highlighting initiatives by engineering students in Mexico.
Ranjeeth and Padayachee (2024)	Computer programming competency	Factors influencing competency	Identifies factors that influence programming skills in higher education, with a focus on students in Information Technology programs.
Yeslyamov (2024)	Software robots and AI	Educational process	Examines the use of software robots and AI technologies in the university-level educational process.
Donnermann and Lugrinr (2024)	Social robotic tutor	Personalization in education	Introduces a model for personalizing the behavior of a social robotic tutor using self-determination theory and empirical findings.
Talisainen et al. (2024)	Telepresence robots	Challenges in remote communication	Compare the use of telepresence robots and videoconferencing software for remote communication in higher education settings.
Cui et al. (2022)	Human-robot interaction (HRI)	Prediction of student engagement	Presents a model for predicting student engagement in higher education through HRI, with high accuracy in evaluating participation and learning outcomes.
Abidin et al. (2021)	Low-cost educational robotics	STEM education promotion	Explores the design of affordable educational robots to enhance STEM teaching, supporting integrated learning in science, technology, engineering, and mathematics.
Bampasidis et al. (2021)	Underwater robotics	Development of STEM skills	Analyzes the impact of the Hydrobots project on STEM education, encouraging engineering learning and the application of design methodologies in education.

4.3 Opportunities for future work

The development of hybrid and personalized learning environments represents an opportunity for the expansion of educational robotics. The combination of telepresence robots with digital platforms can optimize teaching in various settings, from remote education to continuing education programs (Hu et al., 2024; Kasuk and Virkus, 2024). Findings suggest that investment in research and development will enhance the adaptability of educational robots and their integration with other technological tools.

The advancement of artificial intelligence in education also opens new possibilities for the evolution of educational robotics. Combining AI with social robots has the potential to deliver more interactive and adaptive learning experiences, personalizing instruction according to individual student needs (Leoste et al., 2021a; Chaka, 2023). However, implementation must take into account ethical and pedagogical considerations to ensure appropriate use and alignment with educational goals (Aler Tubella et al., 2024; Bond et al., 2024).

Furthermore, educational robotics has proven effective not only in technical learning but also in strengthening transversal skills such as creativity, problem-solving, and teamwork (Rebelo, 2025). The collected evidence indicates that its integration in higher education has the potential to transform teaching, provided current challenges are addressed and a strategic adoption is promoted based on ongoing research and development.

5 Conclusions

The review showed that educational robotics in higher education has evolved from its initial use in programming instruction to becoming a tool that enhances student engagement, STEM learning, and personalized instruction through human-robot interaction models and telepresence. Its application has demonstrated benefits not only in the development of technical skills but also in transversal competencies such as problem-solving and teamwork. However, its implementation continues to face challenges related to infrastructure, teacher training, and the inclusion of students with special needs, which limits its large-scale adoption.

The limitations of this review include the availability of recent studies and the lack of longitudinal evaluations regarding the long-term impact of robotics on learning. Looking ahead, further research is recommended on its integration with artificial intelligence and the effectiveness of hybrid methodologies in higher education. Additionally, the development of more accurate metrics to assess its impact would help consolidate strategies that optimize its use and support a more accessible and personalized education.

Author contributions

PZ: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. AL: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. JB: Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing. FA-C: Conceptualization, Data curation, Project administration, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Gen AI was used in the creation of this manuscript. The author(s) acknowledge the use of ChatGPT-4o for language editing; however, the content, interpretations, and conclusions presented in this work are solely the responsibility of the author(s).

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