International Journal of Engineering Insights: (2025) Vol. 3, Nro.1, Regular Paper
https://doi.org/10.61961/injei.v3i1.29

Augmented Reality Systems for Enhancing Robotic Manipulator Learning

Cristian P. Chuchico · Diego Bustillos

Received: 05 Feb 2025 / Accepted:16 May 2025 / Published: 15 Nov 2025

Abstract: Augmented Reality (AR) has emerged as a transformative technology in education by integrating digital information into physical environments. This study presented the development of an AR platform designed to teach robotic manipulator concepts to engineering students. The system provided interactive 3D visualizations of joint configurations, degrees of freedom (DoF), kinematic models, and safety workspaces. A quasi-experimental study with a pretest–posttest design (n = 60) was conducted at Universidad de las Fuerzas Armadas ESPE. The results showed a significant improvement in student performance, with an average increase of approximately 40% in test scores. A paired t-test confirmed that the difference between pretest and post-test results was statistically significant ($p < 0.05$). Additionally, user perception results indicated high acceptance levels, with an overall satisfaction rate of 88%. These findings suggest that AR-based learning environments can effectively enhance the understanding of complex robotic concepts in engineering education.

Keywords Augmented Reality · Robotics Education · Interactive Learning Environments · Industry 4.0 · Kinematics Visualization

1 Introduction

Augmented Reality (AR) has emerged as a transformative technology that integrates digital information into physical environments through multimodal interaction. Unlike Virtual Reality (VR), which creates fully synthetic environments [1], AR enhances real-world perception by overlaying interactive elements such as visual, auditory, and haptic feedback, while preserving the user's contextual immersion [2,3]. Over the past decade, AR has expanded beyond entertainment and has been increasingly adopted in strategic domains including Industry 4.0, education, smart manufacturing, healthcare, and engineering training. [4,5,6,7,8,9]

In educational contexts, AR has demonstrated significant potential to improve the understanding of complex and abstract concepts by enabling interactive and spatial visualization [10,11]. By transforming abstract models such as molecular structures or kinematic systems into manipulable representations, AR reduces cognitive load and optimizes the transfer of knowledge [12, 13]. In engineering education, particularly in robotics, the comprehension of concepts such as kinematics, degrees of freedom (DoF), and safety workspaces often represents a challenge due to their abstract nature. AR-based systems address this by providing intuitive and immersive representations that facilitate cognitive processing and knowledge retention [14,15].

However, despite the growing adoption of AR in education, there remains a lack of integrated platforms specifically designed for teaching industrial robotic manipulators that combine kinematic visualization, safety analysis, and interactive exploration within a unified environment [16,17]. Additionally, limited empirical evidence exists regarding the quantitative impact of such systems on student learning outcomes in real laboratory settings.

To address this gap, this study developed and implemented an AR-based learning platform focused on the Mitsubishi RV-2SDB robotic manipulator [18]. The system, which utilizes a smartphone and a Bluetooth-connected pointer, allows students to interact with virtual representations of the robot's structure, kinematics, and safety zones without requiring direct physical manipulation. A quasi-experimental pretest–posttest design was employed to evaluate its effectiveness in improving student learning metrics.

Cristian P. Chuchico
Escuela de Doctorado, Programa de Doctorado en Ingeniería Electrónica, Universidad de Zaragoza, Zaragoza, España.
E-mail: 980122@unizar.es

Diego Bustillos
Universidad de las Fuerzas Armadas - ESPE, Latacunga, Ecuador.
E-mail: dibustillos@espe.edu.ec

The remainder of this paper is organized as follows: Section 2 describes the system development and architecture. Section 3 presents the methodology and evaluation instruments. Section 4 discusses the statistical results and findings. Finally, Section 5 presents the conclusions and future work.

2 Project Development

The development of the proposed Augmented Reality (AR) system was carried out using the Scrum methodology as an agile framework to support iterative design, continuous testing, and incremental system integration [19,20]. This approach facilitated efficient coordination of development tasks and ensured adaptability to evolving technical requirements.

During each development cycle, the core modules of the AR platform were implemented and validated, including the integration of AR visualization, user interaction mechanisms, and mobile interface components. This process enabled the progressive construction of a functional and scalable system.

2.1 AR System Implementation

The AR application was developed using Unity [21] as the primary environment for creating interactive 3D experiences, combined with Vuforia for image recognition and tracking. This configuration enabled the detection of visual markers and the real-time visualization of virtual content associated with the Mitsubishi RV-2SDB robotic manipulator.

The system allows users to access key technical information, including robot structure, kinematic behavior, and safety zones, through an interactive AR interface. This approach enhances the understanding of complex robotic concepts by providing intuitive and immersive visualization.

The 3D model of the Mitsubishi RV-2SDB manipulator was implemented as the central element of the application, as shown in Fig. 1. The initial interface of the system includes a presentation screen and a structured navigation menu, which allows users to access different functional modules, as illustrated in Fig. 2. The main interaction menu is presented in Fig. 3, enabling intuitive navigation between system functionalities.

2.2 Functional Modules

The AR platform was structured into multiple functional modules designed to support the learning of key robotics concepts:

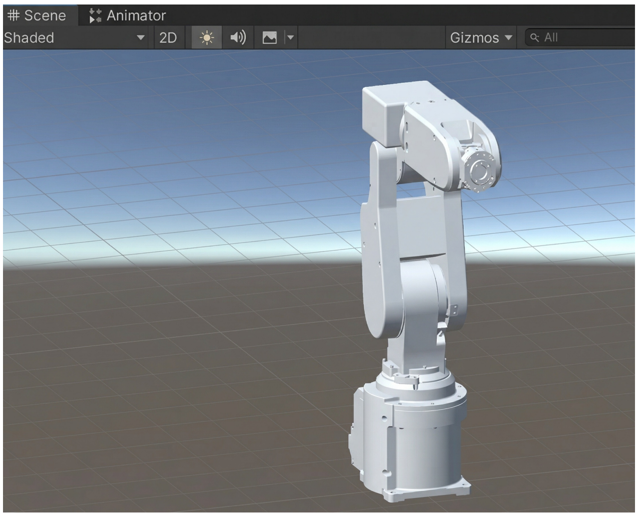


Fig. 1 Modeling of the Mitsubishi RV-2SDB Robot

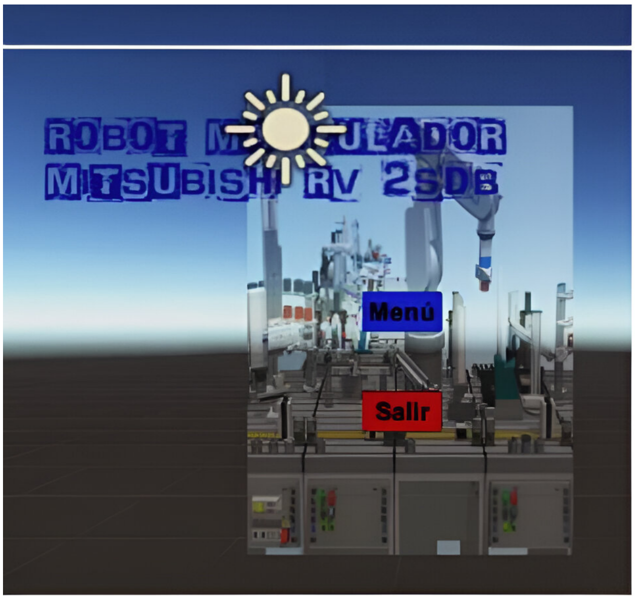


Fig. 2 Application Presentation Interface

2.2.1 Specifications

This module provides access to the main technical parameters of the robotic manipulator, including degrees of freedom, operating range, motion characteristics, and physical constraints. The information is presented in a structured format to facilitate rapid understanding of the system's capabilities, as shown in Fig. 4.

2.2.2 Links and Joints

This module enables the visualization of the manipulator's kinematic chain through AR-based overlays. The system uses visual markers to trigger the display of virtual information associated with each link and joint,

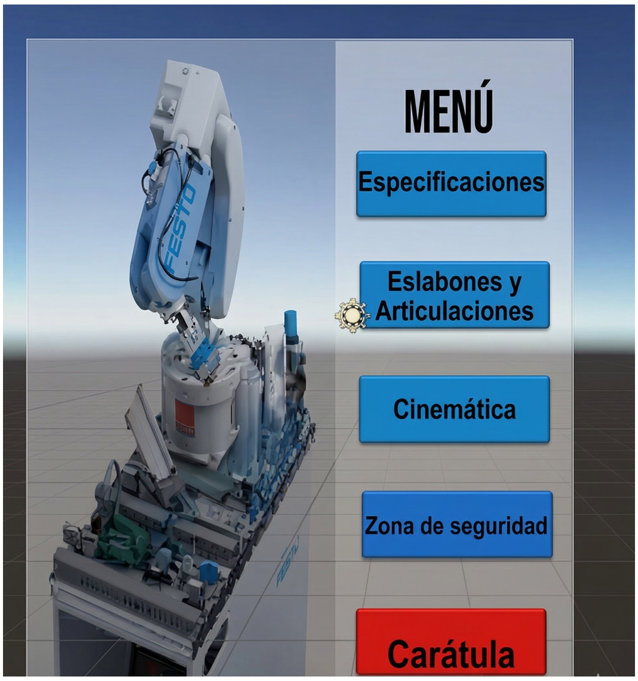
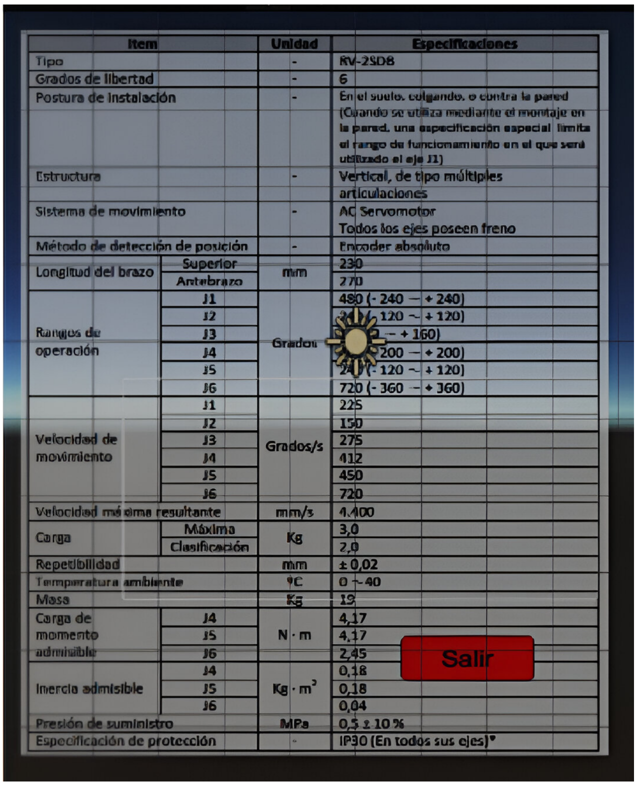


Fig. 3 Main Interaction Menu



Item		Unidad	Especificaciones
Tipo		-	RV-2SD8
Grados de libertad		-	6
Postura de instalación		-	En el suelo, colgando, o contra la pared (Cuando se utiliza mediante el montaje en la pared, una especificación especial limita el rango de funcionamiento en el que será utilizado el eje J1)
Estructura		-	Vertical, de tipo múltiples articulaciones
Sistema de movimiento		-	AC Servomotor Todos los ejes poseen freno
Método de detección de posición		-	Encoder absoluto
Longitud del brazo	Superior	mm	230
	Antebrazo		270
Rangos de operación	J1	Grados	480 (- 240 ― + 240)
	J2		[illegible] 120 ~ + 120)
	J3		[illegible] ― + 160)
	J4		[illegible] 200 ― + 200)
	J5		[illegible] (- 120 ~ + 120)
	J6		720 (- 360 ― + 360)
Velocidad de movimiento	J1	Grados/s	225
	J2		150
	J3		275
	J4		412
	J5		450
	J6		720
Velocidad máxima resultante		mm/s	4,400
Carga	Máxima	Kg	3,0
	Clasificación		2,0
Repetibilidad		mm	± 0,02
Temperatura ambiente		°C	0 ~ 40
Masa		Kg	19
Carga de momento admisible	J4	N · m	4,17
	J5		4,17
	J6		2,45
Inercia admisible	J4	Kg · m²	0,18
	J5		0,18
	J6		0,04
Presión de suministro		MPa	0,5 ± 10 %
Especificación de protección		-	IP30 (En todos sus ejes)*

Fig. 4 Technical Specifications of the Mitsubishi RV-2SDB Manipulator

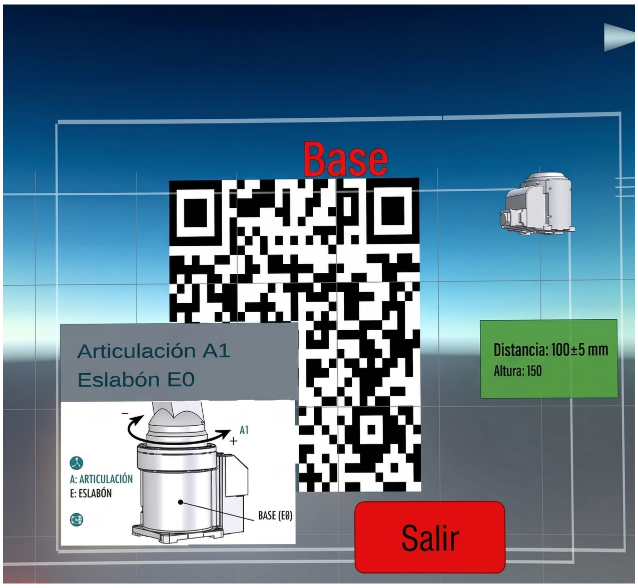


Fig. 5 Links and Joints Visualization

allowing users to explore the robot structure in real time. This functionality improves spatial understanding without requiring direct physical interaction. The visualization is presented in Fig. 5.

2.2.3 Forward Kinematics

The forward kinematics module presents the relationship between joint parameters and the position of the end-effector using the Denavit–Hartenberg (D–H) formulation. This approach enables the representation of the manipulator through homogeneous transformation matrices, facilitating the analysis of its kinematic behavior.

The D–H parameters used in the system are summarized in Table 1, while the corresponding visualization within the AR environment is shown in Fig. 6.

Table 1 Denavit-Hartenberg (D-H) Parameters for the Mitsubishi RV-2SDB.

Link (i)	$\boldsymbol{\theta_i}$	d_i **(mm)**	a_i **(mm)**	$\boldsymbol{\alpha_i}$ **(rad)**
1	θ_1	300	0	$-\pi/2$
2	$\theta_2 - \pi/2$	0	250	0
3	θ_3	0	160	0

2.2.4 Safety Zone

This module illustrates the operational workspace of the robotic manipulator, including safe and restricted

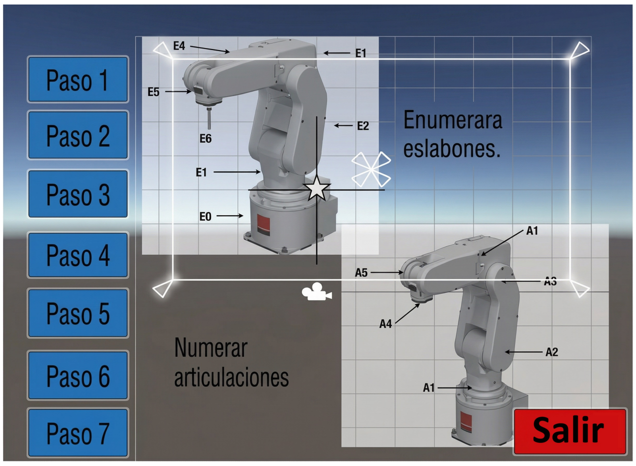


Fig. 6 Forward Kinematics Representation using D-H Parameters

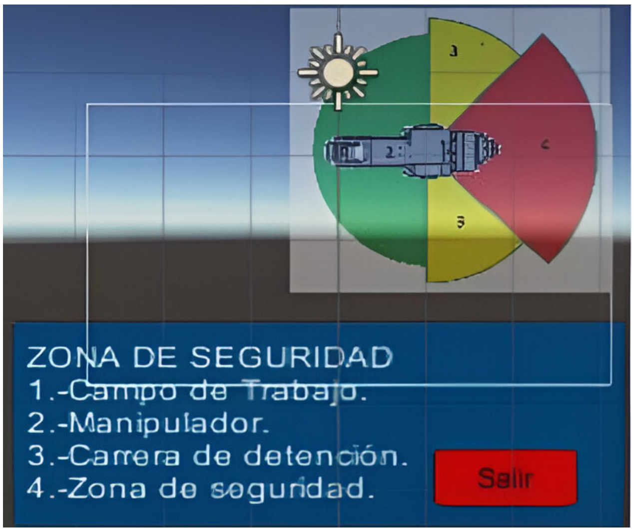


Fig. 7 Safety Zones of the Manipulator

areas. It allows users to identify motion limits and understand safety constraints within the working environment. This feature contributes to risk reduction and improves awareness of safe operation practices. The safety zones are visualized in Fig. 7.

3 Methodology

3.1 Study Design and Participants

This study employed a quasi-experimental design with a single group using a pretest–posttest approach ($n = 60$). The participants were undergraduate students enrolled in the Electromechanical Technology program at Universidad de las Fuerzas Armadas ESPE. A non-probabilistic purposive sampling method was used to ensure that all participants had a similar academic background in robotics and kinematics.

A control group was not included due to institutional constraints, as all students were required to have equal access to the AR-based intervention. Therefore, each participant served as their own control, with pretest scores used as a baseline for comparison.

3.2 Evaluation Instruments

Two instruments were used to assess the effectiveness of the proposed system:

Technical Knowledge Assessment: A structured questionnaire consisting of 10 items was designed to evaluate three key competencies: (i) identification of degrees of freedom and joint configurations, (ii) application of Denavit–Hartenberg parameters, and (iii) understanding of safety zones. Each item was scored on a scale of 0–2, resulting in a maximum score of 20 points.

To ensure comparability, both pretest and posttest were designed with equivalent levels of difficulty and aligned with the same learning objectives.

User Perception Survey: A Likert-scale survey (1–5) was administered to evaluate usability, clarity of information, and perceived learning effectiveness.

Content validity of the instruments was established through expert evaluation by three faculty members specializing in robotics and automation.

3.3 Experimental Procedure

The experimental process was conducted in four stages:

1. **Pretest:** Participants completed an initial assessment to determine baseline knowledge.
2. **System Introduction:** A brief orientation session was conducted to familiarize participants with the AR interface and interaction mechanisms.
3. **Intervention:** Participants engaged in a 45-minute hands-on session using the AR platform, interacting with virtual representations of the robotic manipulator.
4. **Posttest and Survey:** After the intervention, participants completed the posttest and the perception survey.

3.4 Data Analysis

To evaluate the effectiveness of the intervention, a paired t-test was conducted to compare pretest and posttest scores. The level of statistical significance was set at $\alpha = 0.05$.

Additionally, descriptive statistics, including mean and standard deviation, were calculated to analyze performance trends. The percentage improvement between pretest and posttest scores was also computed to quantify learning gains.

This analytical approach ensures that the observed differences in performance are statistically validated and not attributable to random variation.

4 Results and Discussion

This section presents the quantitative results obtained from the experimental evaluation of the proposed Augmented Reality (AR) system, focusing on both learning performance and user perception.

4.1 Learning Performance Analysis

The results of the technical knowledge assessment are summarized in Table 2. A clear improvement can be observed between pretest and posttest scores across all participants.

The mean score increased from 3.20 to 4.50, representing an improvement of approximately 40.6%. Additionally, the standard deviation decreased from 0.65 to 0.38, indicating a more consistent performance after the intervention.

Table 2 Consolidated results of the technical knowledge assessment ($n = 60$).

Metric	Pretest	Posttest	Improvement
Mean Score (out of 5)	3.20	4.50	40.6%
Standard Deviation	0.65	0.38	-
Performance (%)	64%	90%	+26%

To determine whether the observed improvement was statistically significant, a paired t-test was conducted comparing pretest and posttest scores. The results indicated a statistically significant difference between both conditions ($p < 0.05$), confirming that the observed improvement is unlikely to be due to random variation.

Furthermore, the fact that all participants showed higher posttest scores suggests a consistent positive effect of the intervention across the entire sample, reinforcing the robustness of the results.

4.2 User Perception Analysis

The results of the user perception survey are summarized in Table 3. The evaluated dimensions, including usability, clarity of information, pedagogical value, and interactivity, show high levels of acceptance among participants.

Table 3 Consolidated User Perception Survey (Likert Scale: 1–5).

Dimension	Mean	Acceptance (%)
Application Design	4.65	93%
Ease of Use (Usability)	4.70	94%
Information Clarity	4.58	91.6%
Pedagogical Value	4.75	95%
Interactivity	4.40	88%

4.3 Discussion

The observed improvement in learning outcomes can be attributed to the immersive and interactive nature of the AR platform. By enabling real-time visualization of abstract concepts such as kinematics and safety zones, the system facilitates cognitive processing and enhances conceptual understanding.

The reduction in score variability after the intervention suggests that the platform not only improves average performance but also contributes to more uniform learning across participants. Additionally, the high levels of user acceptance indicate that the system is both usable and engaging, which are critical factors for successful integration of emerging technologies in educational environments. Overall, the combination of statistically significant learning gains and positive user perception supports the effectiveness of AR as a tool for enhancing robotics education.

5 Conclusions

This study presented the development and evaluation of an Augmented Reality (AR)-based learning platform for teaching robotic manipulator concepts. The system integrates interactive visualization of kinematic structures, degrees of freedom, and safety zones, providing an intuitive and immersive learning environment.

The experimental results demonstrated a significant improvement in student performance, with an average increase of approximately 40% between pretest and posttest scores. Statistical analysis using a paired t-test confirmed that this improvement was significant ($p <$

0.05), indicating that the observed learning gains are not attributable to random variation.

In addition to the quantitative results, user perception analysis revealed high levels of acceptance in terms of usability, clarity of information, and pedagogical value. These findings suggest that the proposed AR platform effectively supports the understanding of complex robotic concepts and enhances student engagement in laboratory environments.

Overall, this work highlights the potential of AR technologies as effective tools for engineering education, particularly in domains that require spatial reasoning and interaction with complex systems.

Future work will focus on extending the platform to multi-robot environments, integrating advanced AR devices such as head-mounted displays, and incorporating additional features such as haptic feedback and remote collaborative capabilities to further enhance the learning experience.

References

1. M. Walker, T. Phung, T. Chakraborti, T. Williams, and D. Szafir, "Virtual, augmented, and mixed reality for human-robot interaction: A survey and virtual design element taxonomy," *ACM Transactions on Human-Robot Interaction*, vol. 12, no. 4, pp. 1–39, 2023.
2. F. Navarro, A. Martinez, and M. J. M, *Realidad Virtual y Realidad Aumentada Desarrollo de Aplicaciones*. RA-MA, 2018.
3. F. A. Chicaiza, C. Gallardo, C. P. Carvajal, W. X. Quevedo, J. Santana, V. Morales, and V. H. Andaluz, "Real–time virtual reality visualizer for unmanned aerial vehicles," *Augmented Reality, Virtual Reality, and Computer Graphics*, vol. 10851, 2016.
4. V. Andaluz, F. A. Chicaiza, A. Meythaler, D. R. Rivas, and C. P. Chuchico, "Construction of a quadcopter for autonomous and teleoperated navigation," *Conference on Design of Circuits and Integrated Systems (DCIS)*, 2015.
5. A. Quiroz, "Agricultura 4.0: uso de tecnologías de precisión y aplicación para pequeños productores," *Informador técnico*, vol. 87, no. 2, pp. 195–211, 2023.
6. R. Gustavo, "Diseño de guía para la aplicación de realidad aumentada en el proceso de diseño industrial." *Universidad de Querétaro*, 2023.
7. T. Rericha, M. Vacha, F. Steiner, and J. Tupa, "Proceedings of the 2024 international conference on diagnostics in electrical engineering (diagnostika)," in *Diagnostika 2024 - 2024 International Conference on Diagnostics in Electrical Engineering, Proceedings*. Pilsen, Czech Republic: IEEE, 2024.
8. J. J. Fuertes, R. González-Herbón, J. R. Rodríguez-Ossorio, G. González-Mateos, and S. Alonso, "Guidelines to develop demonstration models on industry 4.0 for engineering training," *International Journal of Computer Integrated Manufacturing*, 2023.
9. A. Konstantaras, E. Maravelakis, K. I. Dalaka, E. Duca, and G. Giannakakis, "Educational robotics and agile learning: A review," in *EEITE 2025 - 6th International Conference in Electronic Engineering and Information Technology*. Chania, Greece: IEEE, 2025.
10. A. Álvarez-Marín and J. A. Velazquez-Iturbide, "Augmented reality and engineering education: A systematic review," *IEEE Transactions on Learning Technologies*, vol. 14, no. 6, pp. 817–831, 2022.
11. C. Pasalidou, C. Lytridis, A. Tsinakos, and N. Fachantidis, "Augmented reality and robotics in education: A systematic review," *Computers in Human Behavior: Artificial Humans*, vol. 4, p. 100157, 2025.
12. J. Cabrero-ALmenara, I. de la Horra, M. Galinsoga, V. Marín, F. Navarro, J. Sanchez, and S. Recio, *La realidad aumentada como herramienta educativa, aplicación a la educación infantil, primaria, secundaria y bachillerato*. Ediciones Paraninfo, 2018.
13. J. Almenara, B. Robles, and V. Díaz, "Dispositivos móviles y realidad aumentada en el aprendizaje del alumnado universitario," *RIED. Revista Iberoamericana de Educación a Distancia*, vol. 20, no. 2, pp. 167–185, 2017.
14. M. Mendoza, R. Cruz, A. Villalba, J. Calderon, and A. Erika, "Aplicación de la realidad aumentada para la enseñanza de la robótica," *Pistas Educativas*, vol. 39, no. 127, 2018.
15. S. Ding, T. Lu, X. Lv, Y. Zhang, and R. Deng, "Augmented reality for enhancing educational experience in laboratory safety training," *Journal of Loss Prevention in the Process Industries*, 2026.
16. Z. ZHU, C. LIU, and X. XU, "Visualisation of the digital twin data in manufacturing by using augmented reality," *RIED. Revista Iberoamericana de Educación a Distancia*, vol. 81, pp. 898,903, 2019.
17. N. Prokopiuk and P. Falkowski, "Applicability of augmented and virtual reality for education in robotics," *Journal of Automation, Mobile Robotics and Intelligent Systems*, 2022.
18. P. Papcun and J. Jadlovsky, "Mathematical model of robot melfa rv-2sdb," *Emergent Trends in Robotics and Intelligent Systems: Where is the Role of Intelligent Technologies in the Next Generation of Robots?*, pp. 145–154, 2015.
19. P. A. Coelho, F. Casanello, N. Leal, K. Brintrup, L. Angulo, I. Sanhueza, and E. Forcael, "Challenge-based learning and scrum as enablers of 4.0 technologies in engineering education," *Applied Sciences*, vol. 14, no. 21, p. 9746, 2024.
20. D. H. Vicci, "The impact of artificial intelligence on project managers and scrum masters: A review and evaluation study," https://ssrn.com/abstract=5049345, 2024, available at SSRN: 5049345.
21. V. H. Andaluz, F. A. Chicaiza, C. Gallardo, W. X. Quevedo, J. Varela, J. S. Sánchez, and O. Arteaga, "Unity3d-matlab simulator in real time for robotics applications," *Augmented Reality, Virtual Reality, and Computer Graphics*, pp. 246–263, 2016.

SCI-THOTH