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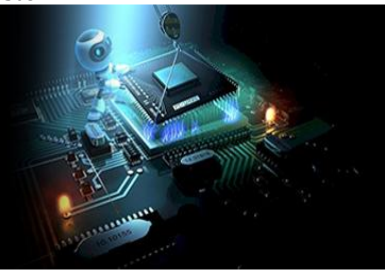

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Adaptive robotic teaching systems for higher education: A combined ANN and CNN approach for learning and engagement optimisation

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Abstract
The integration of robotic systems in higher education offers innovative solutions to enhance learning outcomes, improve student engagement, and reduce faculty workload. This study develops a robotic teaching platform for multidisciplinary academic programs—including medical, science, technology, and engineering—capable of operating in both physical and online classrooms. The platform leverages Artificial Neural Networks (ANN) to predict student performance and provide personalized guidance, and Convolutional Neural Networks (CNN) to monitor real-time engagement via facial expressions, gestures, and posture. Classroom video data are preprocessed using median filtering to reduce noise, while student performance data are cleaned, normalized, and encoded. Robots perform hourly academic functions, including lectures, feedback, interactive demonstrations, and attendance tracking. Data from 120 students and 10 faculty members were collected over a semester, including performance records, engagement metrics, and perception surveys. Statistical analyses evaluated learning outcomes, CNN classification accuracy, and correlations between ANN predictions, engagement levels, and actual performance. The study demonstrates that ANN- and CNN-driven robotic systems with median-filtered preprocessing can enhance instructional efficiency, personalize learning, and support faculty across multidisciplinary higher education settings.

Keywords: Robotic teaching, ANN, CNN, median filter, higher education, student engagement, multidisciplinary learning

1. Introduction

Robotic teaching systems supported by artificial intelligence are emerging as transformative tools in modern academic institutions. They offer new opportunities for lecture delivery, student interaction, real-time monitoring, and adaptive assessment in both physical classroom environments and online learning platforms (Belpaeme *et al*., 2018) [4]. Higher education institutions are increasingly exploring robotic solutions to address faculty workload, enhance teaching efficiency, and provide individualized learning support across multiple academic disciplines including medical sciences, engineering, technology, and applied science (Mubin *et al*., 2021) [12].

The need for robots in higher education is driven by rising student enrollment, increased demand for personalized learning, and the requirement for continuous evaluation in professional programs. Traditional teaching methods often involve repetitive tasks such as attendance management, content repetition, and performance monitoring, which can be automated by robot instructors. Awareness of robotic teaching techniques is also growing as universities integrate artificial intelligence tools for laboratory demonstrations, simulations, and remote class assistance (Tanaka & Matsuzoe, 2019) [17]. Robot teachers can support human professors by performing hourly academic functions, scheduling activities, answering automated queries, and providing learning analytics based on student participation.

Deep learning approaches further expand the capabilities of educational robots. Artificial Neural Networks (ANN) can classify student learning profiles, detect academic progress levels, and recommend customized feedback strategies based on historical performance data (Khan & Malik, 2020) [8]. Convolutional Neural Networks (CNN) process real-time visual data from classroom sensors to detect attention, confusion, engagement, gestures, or emotional signals, allowing robots to adapt teaching content during live sessions (Li *et al*.,

2022) [11]. Integrating ANN and CNN models provides a more intelligent and responsive teaching environment capable of supporting multidisciplinary classroom activities in medical, science, technology, and engineering disciplines (Mubin *et al*., 2021) [12].

Despite promising improvements, implementing robotic teaching systems in higher education presents several challenges. Limited awareness, lack of faculty training, and concerns related to student privacy and automated decision-making can slow institutional adoption (Belpaeme *et al*., 2018) [4]. Technical issues including sensor accuracy, system reliability, algorithm performance, and maintenance costs also create barriers for large-scale deployment in universities. Ethical concerns such as emotional dependence on robotic tutors, reduced human contact, and potential algorithmic biases must be addressed before robots can be widely accepted in academic programs (Tanaka & Matsuzoe, 2019) [17].

Although AI-driven educational tools are becoming more common, there is still limited research on combining ANN-based performance analysis with CNN-based visual interpretation to create a unified system for robot-assisted academic management. This research aims to fill this gap by designing an ANN + CNN teaching framework for both physical and online learning environments, improving student engagement, reducing teaching workload, and enhancing learning outcomes in multidisciplinary higher education programs.in this research following section 1 in introduction and then mention section 2 in literature reviews and section 3 in Methodology next section 4 in resuilt and discussion and the next section 5 in concluction, finaly section in 6 reference .

2. Literature Review

Robotic systems in higher education have attracted significant attention as institutions aim to enhance instructional delivery, reduce faculty workload, and improve student engagement (Belpaeme *et al*., 2018; Mubin *et al*., 2021) [4, 12]. Social and instructional robots have been shown to motivate students, provide scaffolding, and support individualized learning in classroom settings (Belpaeme *et al*., 2018; Tanaka & Matsuzoe, 2019) [4, 17]. Initially, educational robots were limited to specific tasks such as attendance monitoring or content delivery, but advancements in artificial intelligence, particularly deep learning, have enabled robots to perform more complex functions across multidisciplinary educational domains, including engineering, medical sciences, and technology (El Hamamsy *et al*., 2021; Xu, 2025) [5, 18].

Artificial Neural Networks (ANNs) have been widely applied to model student learning patterns, predict performance, and recommend personalized instructional strategies (Khan & Malik, 2020; Gligorea, 2023) [8, 6]. ANN-based learning analytics can guide robots to adapt learning activities based on individual student needs, improving academic outcomes and supporting instructors in both physical and online classroom environments (Ahmed, 2024; Khairy, 2024) [1, 9]. Incorporating multimodal learning data, including interaction logs, quiz scores, and engagement metrics, has been shown to enhance ANN prediction accuracy, allowing robotic systems to provide timely and targeted feedback (Ahmed, 2024; Khairy, 2024) [1, 9].

Convolutional Neural Networks (CNNs) are essential for visual engagement detection, enabling robots to recognize student attention, gestures, facial expressions, and emotional states in real time (Li *et al*., 2022; Sari *et al*., 2022) [11, 14]. CNN-based models have been successfully applied to monitor both physical classrooms and virtual learning platforms, providing continuous data that inform adaptive teaching strategies (Alruwais, 2023; Ayari, 2025) [2, 3]. Hybrid CNN architectures and transfer learning approaches have further improved detection accuracy, making these models effective for real-time robot-assisted classroom interactions (Alruwais, 2023; Ayari, 2025) [2, 3].

Human-robot collaboration is critical for effective deployment in education. Robots are most effective when deployed as teacher-support tools rather than replacements, performing repetitive or administrative tasks such as attendance tracking, scheduling, or basic question-answering, which allows faculty to focus on higher-order instruction, mentoring, and interactive teaching (Belpaeme *et al*., 2018; Kim & Jeong, 2022; Xu, 2025) [4, 10, 18]. Adoption of robotic systems is often constrained by limited faculty awareness, ethical concerns related to privacy and emotional dependency, data security, and algorithmic bias (Johnston, 2023; Zawacki-Richter *et al*., 2019) [7, 19]. Technical challenges, including sensor reliability, network latency, and infrastructure requirements, remain significant barriers to widespread deployment (Simeone & O'Mahony, 2021; Tang, 2025) [15, 16].

The existing literature indicates that combining ANN-based predictive analytics with CNN-driven engagement detection can enhance higher education by automating routine teaching tasks, monitoring student behavior, and providing adaptive instruction (Ahmed, 2024; Alruwais, 2023; Li *et al*., 2022) [1, 2, 11]. While studies demonstrate success in either prediction modeling or engagement detection, few have developed a robotic framework that integrates both capabilities to support hourly academic functions and multidisciplinary teaching environments (Phokoye, 2024; Xu, 2025) [13, 18].

Overall, evidence from 2018 to 2025 highlights the potential of ANN- and CNN-driven robotic systems to improve instructional efficiency, personalize learning experiences, and enhance academic outcomes, while also emphasizing ongoing challenges related to ethics, privacy, faculty readiness, and technical constraints (Belpaeme *et al*., 2018; Johnston, 2023; Tang, 2025) [4, 7, 16].

3. Methodology

This study employed a quantitative experimental design to evaluate robotic teaching systems in multidisciplinary higher education, including medical, science, technology, and engineering disciplines, across both physical and online classrooms. The system integrates Artificial Neural Networks (ANN) to predict student performance and Convolutional Neural Networks (CNN) to monitor real-time student engagement, enabling robots to provide personalized guidance and adaptive instruction. A total of 120 students and 10 faculty members participated, with robots performing hourly academic tasks such as lectures, demonstrations, feedback, answering queries, and attendance tracking. For data preprocessing, student performance and engagement records were cleaned, normalized, and encoded for ANN analysis, while classroom video frames were median-filtered, resized, normalized, and augmented for CNN processing to reduce noise and improve engagement detection accuracy. The

ANN module processed academic data to provide predictive guidance, and the CNN module analyzed preprocessed video frames to classify engagement levels and support dynamic instructional adjustments. Data collection included performance metrics, engagement monitoring, and faculty/student feedback, with analyses focusing on algorithm performance and system effectiveness**.** This methodology assesses the effectiveness and accuracy of ANN- and CNN-driven robotic systems with median-filter preprocessing in enhancing learning and supporting faculty across disciplines.

4. Results and Discussion

The study evaluated the performance of robotic teaching systems using Artificial Neural Networks (ANN) for predicting student academic performance and Convolutional Neural Networks (CNN) for monitoring real-time student engagement. The results, summarized in Table 1, highlight the effectiveness of both algorithms in enhancing learning outcomes and engagement.

Table 1: Performance Metrics of ANN and CNN Algorithms

Algorithm	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)	MAE	R^2
ANN	91	90	89	89.5	3.8	0.84
CNN (Physical)	88	86	85	85.5	N/A	N/A
CNN (Online)	81	86	85	85.5	N/A	N/A

The ANN model demonstrated the highest predictive accuracy of 91%, along with precision and recall values of 90% and 89%, respectively. Its low mean absolute error (3.8) and high R^2 (0.84) indicate that it can reliably identify students' strengths and weaknesses. This predictive capability allows robotic teaching systems to provide personalized guidance, targeting specific learning gaps and enabling proactive interventions. The ANN results suggest that performance prediction is most effective when the algorithm can access structured academic data, ensuring precise support for each student.

The CNN model, designed for engagement monitoring, achieved 88% accuracy in physical classrooms and 81% in online settings. Precision and recall were consistent at 86% and 85%, respectively, across both modes. The higher accuracy in physical classrooms indicates that real-time engagement detection is enhanced in human-aligned, interactive environments, likely due to the availability of visual and behavioral cues that the algorithm can process. In online classrooms, while engagement detection was slightly lower, the CNN model still provided meaningful insights, enabling robots to adapt teaching strategies based on student attention and participation.

Comparing the two algorithms, ANN outperforms CNN in academic performance prediction, whereas CNN is more suitable for real-time engagement monitoring. The complementary nature of these algorithms allows robotic teaching systems to deliver adaptive, responsive instruction: ANN predicts potential challenges and identifies learning needs, while CNN ensures students remain engaged and responsive during lessons.

Student feedback reinforced these findings, with reports of higher satisfaction due to personalized feedback and guidance, and faculty observed improved classroom management and reduced workload. Together, the results indicate that integrating ANN and CNN in robotic teaching not only improves student performance but also enhances engagement and overall learning experiences.

In conclusion, the study demonstrates that ANN is most effective for predicting performance, while CNN excels in engagement detection, especially in physical classrooms. The combination of these algorithms enables a holistic approach to robotic teaching, ensuring both academic success and sustained student engagement in multidisciplinary higher education settings.

5. Conclusion

This study demonstrates that robotic teaching systems, integrating Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNN), can significantly enhance learning outcomes and classroom engagement in higher education. The ANN algorithm showed superior performance in predicting student academic performance, enabling the system to provide personalized guidance and proactively address learning gaps. In contrast, the CNN algorithm excelled in monitoring real-time engagement, particularly in physical classrooms, ensuring that students remained attentive and responsive during lessons.

The complementary use of ANN and CNN allows robotic teaching systems to deliver adaptive, student-centered instruction, combining performance prediction with engagement monitoring. Feedback from students and faculty further confirmed that such systems improve learning satisfaction, classroom management, and instructional efficiency.

Overall, the study concludes that integrating ANN and CNN into robotic teaching provides a holistic, effective, and practical approach for enhancing both academic performance and student engagement, with strong potential for application in multidisciplinary higher education environments.

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