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An Effective Virtual Reality Paradigm for Robotic Assembly in First-Year Engineering Curriculum

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Abstract— **An effective Augmented Reality and Virtual Reality paradigm is proposed to facilitate introductory robotics course in the first-year engineering curriculum. The AR/VR Application utilization and its impact on the students' learning with respect to robotic assembly and robotic application programming is emphasized in this article. The paper delves into a comprehensive review of the related works presented in the literature. The requirements for the physical assembly and virtual assembly of movable robots are meticulously highlighted. To facilitate course learning a robotic workshop involving steps introduction to robotics, and practical experience on the robot is conducted. The delivery of the course content is made much more effective by inculcating the Virtual experience of the Robotic assembly process. The virtual robotic assembly and manual physical robotic assembly process processes have their own uniqueness and importance and it is left to the students to pick them on a priority basis. Finally, the effectiveness of the proposed course is determined by conducting an online quiz, collecting student feedback, tabulating and analyzing the results. The results demonstrate the effectiveness of the proposed method in creating interest in robotics and related courses among first-year engineering students.**

Keywords— Augmented Reality(AR), Virtual Reality(VR), Build Your Own Robot(BYOR), Robotic assembly.

I. INTRODUCTION

In the context of assembly tasks, a significant advancement has been made through the utilization of Augmented Reality (AR). This technology offers a unique "magic-lens" perspective on physical objects, resulting in a notable reduction in the complexity of assembly processes. When employing AR for assembly tasks, individuals are guided through a predefined sequence of actions with minimal informational input required. Consequently, there exists a compelling rationale for harnessing the continual advancements in AR technology to enhance the learning experience for assemblers. By integrating AR, physical objects can be transformed into intelligent entities capable of communication and interaction with users. This transformation empowers assemblers to acquire a deeper understanding of the technology, going beyond mere hardware components to gain insights into the intricacies of embedded computing and software components. In a recent study, a Pedagogical Virtual Machine (PVM) was employed to assess the effectiveness of AR-based learning. The findings unequivocally conveyed that the PVM combined with AR yielded superior results in terms of learning achievement, enjoyment of learning activities, and overall

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usefulness, in comparison to conventional paper-based approach(AlNajdi, S.M., 2020).

In the realm of high-mix low-volume manufacturing, robots play a pivotal role due to their remarkable versatility and unwavering precision in executing manufacturing tasks. Nevertheless, the widespread adoption of robots has been hindered by the arduous nature of programming and the need for skilled operators. This document delves into the Augmented Reality (AR) assisted robot programming system (ARRPS), which represents a groundbreaking solution offering swifter and more intuitive robot programming in contrast to traditional methods. ARRPS is meticulously crafted to empower less skilled programmers to effortlessly perform robotic tasks. The system relies on sensor data and sophisticated algorithms for critical robotic functions. This novel approach streamlines the process of programming robotic paths and tasks, enabling users to concentrate solely on task definition(Ong, S. K., 2020).

The process of assembly holds a pivotal role within the manufacturing domain, serving as a fundamental and resource-intensive stage that significantly influences the ultimate quality of the product. It is both time-consuming and financially demanding. Augmented Reality (AR) emerges as a pivotal technological asset for aiding workers in the assembly process, primarily due to its capability to deliver real-time instructions and information, seamlessly overlaying them onto the working environment. Numerous implementations of AR have surfaced, championed by both industry leaders and academic institutions, designed to enhance both manual and collaborative assembly efforts. This keynote presentation endeavors to furnish a valuable overview by examining the latest applications of AR within assembly systems. It aims to elucidate the potential advantages while also addressing the present constraints and offering insights into future prospects within this evolving field(Dalle Mura, M., 2021).

In the present day, the realm of robotics applications has transcended the confines of industrial, rigid production environments and research laboratories. Instead, it has permeated various domains where human interaction is a pivotal requirement. Within this evolving landscape, it becomes imperative to educate all users in the utilization and comprehension of robotic systems. Such education plays a pivotal role in ensuring the social acceptance and widespread adoption of robots. In this paper, we focus our attention on the potential applications of VR/AR technologies in the realm of teaching robotics and facilitating training on specific robot platforms. Our aim is to provide a comprehensive review of the available educational resources and to engage in a discourse surrounding their respective advantages and disadvantages. All of this is approached from the perspective of promoting "inclusive robotics," where accessibility and inclusion are paramount considerations(Pozzi, M., 2021).

In recent times, the rapid advancements in computational technology have ushered in an era where artificial intelligence (AI) is seamlessly integrated into virtually every sector and industry. This swift evolution in AI, coupled with the progress in sensing technologies, has ignited a transformation within the realm of robotics. Simultaneously, the proliferation of augmented reality (AR) applications has been instrumental in addressing various challenges across the spectrum of robotics applications. AR is instrumental in demystifying robot motion intent, facilitating intuitive control, and providing valuable feedback to users. Our analysis encompasses a total of 29 papers, examined from two key perspectives: first, a theme-based exploration that elucidates the interconnectedness of AR and AI, and second, an application-based assessment that highlights the transformative impact of these technologies on specific robotics applications. These two sections further delve into the categorization of robotics platforms and the types of applications they address. Our scrutiny of the body of work reveals significant insights and emphasizes prevalent limitations that currently constrain the field. Additionally, our findings underscore the potential of AR and AI integration in resolving the model-mismatch paradigm, a pivotal step toward establishing a closed feedback loop between users and robots(Bassyouni, Z., 2021).

The primary aim was to assess the efficacy of learning within the AR/VR environment and to gauge its impact on comprehending robotics and nurturing design thinking skills. Within the AR environment, thoughtfully crafted by Vuforia, learners embarked on a journey to disassemble and modify models of TurtleBot2 and RACECAR MN robots, concurrently gaining insights into the intricacies of their components. To gauge comprehension of robotics, quizzes were administered, while a post-assessment aimed to assess the training's effectiveness in enhancing course understanding. The collected data convincingly indicate that students not only acquired a heightened understanding of robot systems but also acknowledged the valuable contributions made by the AR and VR applications. Significantly, integrative thinking was prominently utilized throughout the learning process. This study underscores the potential effectiveness of AR applications and virtual simulators as valuable tools for experiential learning within the realm of robot systems, particularly in online courses. Nevertheless, it's essential to recognize that while these experiences are highly beneficial, they cannot entirely replace hands-on practice with real robots, which remains a crucial component of comprehensive robotics education(Verner, I., 2022).

The utilization of AR and VR for training purposes has gained substantial traction within various industries, offering a safe and effective means of preparing workers for new tasks. In this research endeavor, authors aimed to scrutinize and compare the impacts of AR, VR, and video-based training methodologies on both short-term and long-term objective performance metrics, alongside subjective evaluations, within the context of a manual assembly task. Our findings indicate that concerning objective performance metrics such as task completion time and error count, no discernible differences were observed among the AR, VR, and video-based training approaches. However, when authors delved into the realm of subjective evaluations, intriguing variations surfaced. VR-based training was associated with a notably higher perceived task load and received a lower usability rating when compared to both AR and video-based training paradigms(Daling, L. M., 2023).

Augmented Reality (AR) is a technology that enriches the way we perceive the real world by seamlessly blending virtual objects into imagery captured through various camera technologies. In recent years, there has been a significant surge in the development of AR applications within the field of robotics. The primary objective of this paper is to offer a comprehensive overview of AR research in the domain of robotics, focusing on the five-year span from 2015 to 2019. To structure this review, we have categorized the body of work into four distinct application domains: Medical Robotics: This category encompasses applications such as Robot-Assisted surgery (RAS), prosthetics, rehabilitation, and training systems. Motion Planning and Control: Here, we explore research related to trajectory generation, robot programming, simulation, and manipulation. Human-Robot Interaction (HRI): Within this category, we investigate topics such as teleoperation, collaborative interfaces, wearable robots, haptic interfaces, brain-computer interfaces (BCIs), and gaming. Multi-Agent Systems: This domain explores the utilization of visual feedback to remotely control drones, coordinate robot swarms, and manage robots operating within shared workspaces. To conclude, our review outlines the promising future directions of AR research within the realm of robotics. Notably, this survey encompasses an extensive body of work, encapsulating over 100 research contributions published over the last half-decade(Makhataeva, Z., 2020).

Key points from the Literature

- A Pedagogical Virtual Machine (PVM) was employed to assess the effectiveness of AR-based learning. The study involved an experimental task centered around the assembly and exploration of a modularized mobile robot project named Buzz-Boards.
- Augmented Reality (AR) emerges as a pivotal technological asset for aiding workers in the assembly process, primarily due to its capability to deliver real-time instructions and information, seamlessly overlaying them onto the working environment.
- Focused on the design of an Augmented Reality (AR) assisted robot programming system (ARRPS), which represents a groundbreaking solution offering swifter and more intuitive robot programming in contrast to traditional methods.
- Few potential applications of VR/AR technologies in the realm of teaching robotics and facilitating training on specific robot platforms are explored.
- Reviewed the previous works in two ways, a theme-based exploration that elucidates the interconnectedness of AR and AI, and second, an application-based assessment that highlights the transformative impact of these technologies on specific robotics applications.

Focused on assessing the efficacy of learning within the AR/VR environment and gauging its impact on comprehending robot systems and nurturing integrative thinking skills.

II. OVERVIEW OF AR/VR FOR ROBOTIC ASSEMBLY IN VIRTUAL ENVIRONMENT

Augmented Reality (AR) and Virtual Reality (VR) have emerged as cutting-edge technologies that are revolutionizing the landscape of robotic assembly, particularly within virtual environments. By seamlessly blending the digital and physical worlds, these technologies are driving innovation in assembly processes, training methodologies, and human-robot interactions. This introduction provides an overview of how AR and VR are transforming robotic assembly within virtual environments, their key applications, and the potential impact on this field.

Augmented Reality (AR) in Virtual Robotic Assembly: AR enriches the virtual assembly experience by overlaying digital information onto the user's view of the virtual environment. In the context of virtual robotic assembly, AR offers a range of advantages: Guided Assembly: AR provides real-time visual instructions to users, assisting them in assembling virtual components accurately and efficiently. Users can follow step-by-step guidance, ensuring precise assembly in the virtual realm. Realistic Visualization: AR enhances the realism of the virtual environment, making it easier for users to interact with and manipulate virtual robotic components as if they were tangible objects. Remote Collaboration: AR facilitates remote collaboration by allowing experts to provide guidance and support to users within the virtual assembly environment. This is especially valuable for troubleshooting and collaborative assembly projects. Training and Skill Development: AR-based virtual training environments enable users to practice and refine their assembly skills in a safe, immersive setting. This reduces the learning curve when transitioning to physical assembly tasks.

Virtual Reality (VR) in Virtual Robotic Assembly: VR immerses users in a fully digital, simulated environment, offering a wide range of applications in virtual robotic assembly: Immersive Training: VR provides a high degree of immersion, allowing users to practice complex robotic assembly tasks within a virtual environment. This immersive training enhances user skills and confidence. Complex Scenario Simulation: VR can replicate intricate assembly scenarios that are challenging to reproduce in the physical world. Users can encounter a variety of assembly challenges and develop problem-solving abilities.

Prototype Testing: Engineers can utilize VR to prototype and validate robotic assembly processes virtually. This streamlines the development and optimization of assembly procedures before physical implementation. Human-Robot Interaction Optimization: VR facilitates the design and testing of human-robot collaborative assembly processes, ensuring seamless cooperation between robots and human operators. AR and VR are reshaping the landscape of virtual robotic assembly by improving training effectiveness, enhancing assembly precision, and fostering innovation. As these technologies continue to advance, they are poised to play a pivotal role in shaping the future of robotic assembly within virtual environments, offering unprecedented capabilities and opportunities for automation and training.

A. Augmented Reality in Engineering Education and Robotics

The teaching of engineering makes good use of augmented reality learning activities. For instance, 60 first-year undergraduates majoring in electronics and electrical engineering took part in the study and learnt how to utilise an oscilloscope and function generator in a laboratory course. A control group and an experimental group of students were separated. While the control group was instructed using the standard method utilising the laboratory manual, the experimental group practised using the equipment in an augmented reality environment before using the actual equipment. The study's findings showed that the experimental group significantly outperformed the control group in terms of operation skills, reduced cognitive load, and increased appreciation for the learning experience(Singh, G., 2019).

In recent experiments, augmented reality surroundings were taken into consideration for mobile robots that were learning. The paper (Mejías Borrero, A. 2012) describes an experiment in which students created a mobile robot that was controlled by the GoGo Board and used data from virtual sensors provided by the HoloLens program to operate it in augmented reality. 36 college students who participated in the study were split into experimental and control groups and trained using robots to complete maze navigation tasks. The sensor data were shown to the experimental group's students using augmented reality, whereas the control group's students saw them on a computer screen. According to the study, experimental group students greatly outperformed control group students in terms of learning how to operate a robot(Verner, I., 2022).

The study (Verner, I., 2022) takes into account a lab activity where 20 undergraduate students practised path planning and navigation of the mobile robot Khepera II utilising data provided by AR. The participants valued the AR skills they had developed and how the AR tools helped them study the material(Verner, I., 2022).

The case studies that were discussed did not take into account the pedagogical aspects of learning the subject in AR environments, even if they showed how AR apps may be used in robotics teaching. In the study described in the paper(Melonee, 2010), authors put particular emphasis on these elements and created and implemented augmented reality (AR) practises as an online, remotely accessible practise in investigating contemporary robot systems. Students were given AR experiences to aid in concept learning as well as the growth of integrative thinking abilities for problem-solving in robot assembly, programming, and operation. Intelligent robots of today are intricate, integrated systems that use a variety of disruptive technologies. Students must form connections in order to learn how to create and use these robots(Melonee, 2010).

B. Proposed Virtual Assembly through VR Method

An application for providing the Assembly experience is achieved through the BYOR Virtual app. The application is developed using Unity Programming.

Components used for Manual Robotic Assembly:

- Two Chassis lower and upper.
- Two Wheels with Screws.

- One caster wheel with metallic spacers and screws.
- Motor Clamps with screws.
- Two DC Motors.
- Couplers with grub screws.
- MDD3A motor driver.
- Battery case with three 3.7V lithium-ion batteries.
- Battery protection circuit with single pole switch and connecting wires
- Arduino Uno
- Ultrasound Sensor clamp
- Ultrasound Sensors with screws
- IR Sensor Clamp
- IR Sensors with screws

Virtual components created for Virtual Robotic Assembly:

1. Two Chassis lower and upper
2. Two Wheels with Screws
3. One caster wheel with metallic spacers and screws
4. Motor Clamps with screws
5. Two DC Motors
6. Couplers with grub screws
7. MDD3A motor driver
8. Battery case with three 3.7V lithium-ion batteries
9. Battery protection circuit with single pole switch and connecting wires
10. Arduino Uno
11. Ultrasound Sensor clamp
12. Ultrasound Sensors with screws
13. IR Sensor Clamp
14. IR Sensors with screws

C. About the 3D Model of BYOR Robot

A sample picture of the BYOR robot is as shown in the fig.1

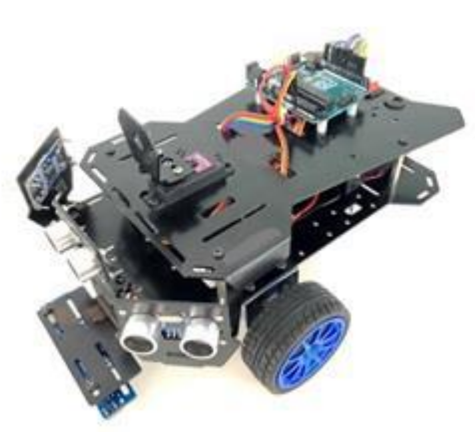

Figure 1. BYOR: Fully Assembled Robot.

D. An Experience with Build Your Own Robot (BYOR)

We created an AR application for researching the BYOR robot system. The benefit of creating the new VR experiential learning is to provide immersive learning through an AR application even when there is no physical robot available.

E. The Robotics Workshop

The manual robotic assembly is a 12-hour course (readers can find the detailed description of the implementation of the course from our previously published article(Praveena K. S., 2023) and the robotic assembly through virtual reality in a virtual reality environment is a 6-hour course. The classroom with 30 students were considered for live hands-on sessions and we ensured that individual involvement of the students through the course in experiencing virtual assembly of BYOR robot. Fig. 2 shows the agenda of the workshop.

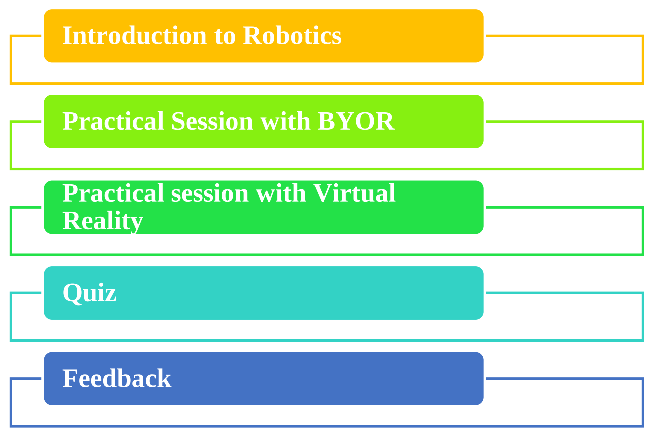

Figure 2. Workshop Outline

Step 1: Introduction to Robotics provides detailed instruction on robotics and its history.

Step 2: A practical session with the Build Your Own Robot includes a short lecture of 15 minutes to help students identify the components and parts of the robot and to facilitate the mechanical assembly of the robot.

Step 3: Practical session with the Build Your Own Robot by using a Virtual Reality application to help students understand the whole assembly process very quickly. The Virtual Reality experience is provided through Android and Apple OS Smartphones.

Here steps number 2 and 3 are interchangeable, because if a student wants to go through the Virtual Reality step first or the Mechanical Assembly step he or she is permitted. The pictorial visualization about the application of Virtual robotic assembly used to create interest among students are shown in the Fig. 3 and Fig. 4.

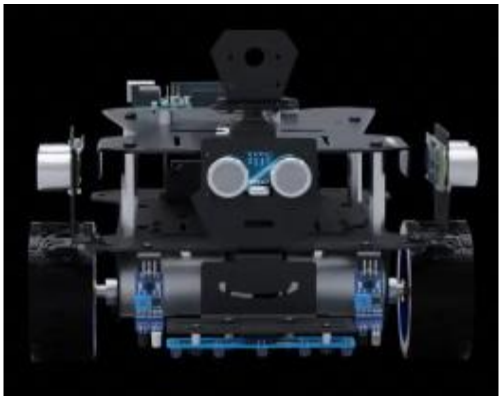

Figure 3. BYOR: Fully Assembled Robot in Virtual Environment.

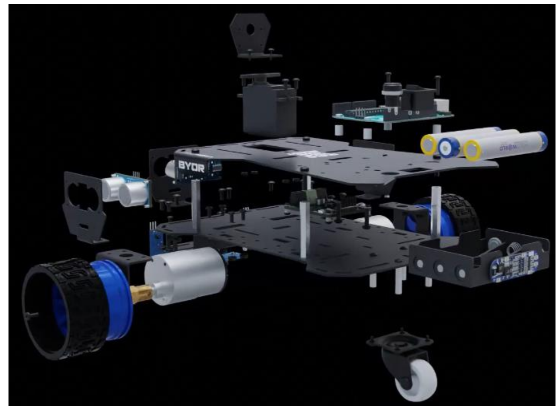

Figure 4. BYOR: Robot with its parts flying in a Virtual Environment.

F. Survey questions

The Table 1 and Table 2 provides the list of questions used in conducting the online quiz and online student feedback respectively.

Table 1: Questions used for Pre and Post Assessment

	Quiz Questions
1.	Which component is commonly used as the foundation for building the structure of a virtual robot?
2.	What type of wheel components are included in the virtual assembly, and how are they attached to the chassis?
3.	Describe the purpose of the caster wheel in the virtual robotic assembly and its specific components.
4.	How are the motor clamps utilized in securing the two DC motors to the virtual chassis?
5.	What is the role of couplers with grub screws in connecting components such as wheels and motors in the virtual assembly?
6.	Identify the key function of the MDD3A motor driver within the virtual robotic system.
7.	Describe the arrangement and connection of the lithium-ion batteries in the virtual battery case.
8.	What safety feature is provided by the battery protection circuit, and how is it controlled in the virtual setup?
9.	Explain the role of the Arduino Uno in the virtual robotic assembly and how it interfaces with other components.
10.	How is the ultrasound sensor clamp employed in securing the ultrasound sensors to the virtual robot?
11.	Specify the purpose of the IR sensor clamp and how it facilitates the integration of IR sensors into the virtual assembly.
12.	Describe the function of the single pole switch in the context of the battery protection circuit within the virtual setup.
13.	Explain the process of connecting the ultrasound sensors to the virtual robot using screws.
14.	In the virtual robotic assembly, how do the IR sensors contribute to the robot's sensing capabilities?
15.	Discuss the significance of the metallic spacers in the assembly and where they are commonly used in the virtual robot.

Table 2: Feedback Questions

1.	How would you rate the overall effectiveness of the virtual reality experience in enhancing your understanding of robotic assembly concepts?
2.	Did the use of virtual reality contribute to a more engaging and interactive learning experience compared to traditional methods?

3.	To what extent did the virtual reality paradigm help you visualize and comprehend complex robotic assembly processes?
4.	Were the virtual scenarios representative of real-world robotic assembly challenges, providing a practical and realistic learning environment?
5.	How well did the virtual reality technology facilitate hands-on experience and experimentation in robotic assembly tasks?
6.	Did the incorporation of virtual reality positively impact your ability to troubleshoot and solve problems related to robotic assembly?
7.	To what extent did the virtual reality component align with the theoretical concepts covered in the first-year engineering curriculum?
8.	Were the instructions and guidance provided within the virtual reality environment clear and conducive to effective learning?
9.	Did the virtual reality experience enhance your collaboration and communication skills when working on robotic assembly projects with peers?
10.	What suggestions do you have for improving the integration of virtual reality into the first-year engineering curriculum for robotic assembly?

III. RESULTS AND DISCUSSIONS

In response to the evolving demands of the educational landscape, a pioneering initiative was undertaken to introduce an augmented/virtual reality paradigm into the first-year engineering curriculum, specifically focusing on robotic assembly concepts. The aim was to provide students with an immersive and interactive learning experience that goes beyond traditional methods, offering a dynamic platform to visualize, comprehend, and engage with complex engineering processes. Each session included both pre- and post-assessments designed to assess students' comprehension of the concepts covered. The use of a pretest established a baseline, enabling us to effectively monitor and measure student progress throughout the session. A consistent set of multiple-choice questions (worth 15 points) was administered at the beginning and end of each session using Google Forms, aligning with the content taught during that specific session. With each class comprising 60 students, Table 3 displays the scores attained by students in the pre-assessment and post-assessment tests for one session. The results indicate that most students demonstrated a clear understanding of the concepts covered in each session based on their responses and scores.

Table 3: Pre and Post Assessment Scores

Particulars	Pre-assessment			Post-assessment		
Marks Scale	0-5	6-10	10-15	0-5	6-10	10-15
No. of students scored (60)	35	25	03	7	11	42

The final feedback questions were shared through google form and results were collected anonymously. It helps us to know about how much students liked the virtual assembly through VR, does it helped them understand things better, and if it was like real engineering challenges. The results shown in table 4 talks about their experiences and what they think could be made better in the future. This information is important because the feedback helps us understand how using AR/VR can make learning about building robots more interesting and easier for students.

Most respondents (85%) rated the overall effectiveness of the augmented/virtual reality experience as highly beneficial. The immersive nature of technology significantly enhanced their understanding of robotic assembly concepts. About 90% of students found the augmented/virtual reality approach more engaging and interactive compared to traditional methods. The dynamic and visually rich environment captured their attention, making the learning experience more enjoyable. Respondents (78%) expressed that the augmented/virtual reality paradigm greatly facilitated their ability to visualize and comprehend complex robotic assembly processes. The 3D simulations provided a clearer understanding of spatial relationships and assembly sequences. A substantial number of students (92%) acknowledged that the virtual scenarios closely resembled real-world robotic assembly challenges. This realism contributed to a practical learning experience, helping bridge the gap between theory and application. Most respondents (87%) agreed that the augmented/virtual reality technology effectively facilitated hands-on experience and experimentation in robotic assembly tasks. The interactive nature of the simulations allowed them to practice and refine their skills in a risk-free environment. Over 80% of students reported that the augmented/virtual reality component positively impacted their ability to troubleshoot and solve problems related to robotic assembly. The interactive nature of technology encouraged critical thinking and problem-solving skills.

The augmented/virtual reality content was deemed to align well with the theoretical concepts covered in the first-year engineering curriculum by 88% of respondents. The integration of virtual scenarios complemented classroom learning, providing a more holistic educational experience.

The clarity of instructions and guidance within the augmented/virtual reality environment received positive feedback from 82% of students. Clear instructions enhanced the learning experience, allowing them to navigate and interact seamlessly within the virtual space.

The collaborative aspects of augmented/virtual reality were appreciated by 75% of students, who noted improved collaboration and communication skills when working on robotic assembly projects with peers. Virtual team environments allowed for effective collaboration, even in remote learning settings.

Some students suggested enhancing the variety of virtual scenarios and incorporating more advanced assembly challenges to further challenge their skills. Additionally, a few respondents recommended expanding the integration of augmented/virtual reality into other engineering courses for a more cohesive learning experience.

Table 4: Students response for impact on learning questionnaire\

Questions	Percentage Distribution				
	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
How would you rate the overall effectiveness of the augmented/virtual reality experience in enhancing your understanding of robotic assembly concepts?	2%	2%	5%	6%	85%
Did the use of augmented/virtual reality contribute to a more engaging and interactive learning experience compared to traditional methods?	2%	3%	1%	4%	90%
To what extent did the augmented/virtual reality paradigm help you visualize and comprehend complex robotic assembly processes?	3%	4%	5%	10%	78%
Were the virtual scenarios representative of real-world robotic assembly challenges, providing a practical and realistic learning environment?	1%	3%	2%	2%	92%
How well did the augmented/virtual reality technology facilitate hands-on experience and experimentation in robotic assembly tasks?	3%	2%	5%	3%	87%
Did the incorporation of augmented/virtual reality positively impact your ability to troubleshoot and solve problems related to robotic assembly?	4%	4%	2%	10%	80%
To what extent did the augmented/virtual reality component align with the theoretical concepts covered in the first-year engineering curriculum?	2%	2%	4%	4%	88%
Were the instructions and guidance provided within the augmented/virtual reality environment clear and conducive to effective learning?	1%	2%	5%	10%	82%
Did the augmented/virtual reality experience enhance your collaboration and communication skills when working on robotic assembly projects with peers?	5%	6%	5%	9%	75%

IV. CONCLUSION

An effective Augmented Reality and Virtual Reality paradigm is proposed to facilitate introductory robotics course at the first-year engineering curriculum. The AR/VR Application utilization and its impact on the students' learning with respect to robotic assembly and robotic application programming is emphasized in this article. The paper delves into a comprehensive review of the related works presented in the literature. The requirements for the physical assembly and virtual assembly of movable robots are meticulously highlighted. To facilitate course learning a robotic workshop involving steps introduction to robotics, and practical experience on the robot is conducted. In conclusion, the feedback on the augmented/virtual reality paradigm in the first-year engineering curriculum for robotic assembly underscores its transformative impact on the learning landscape. Students overwhelmingly attest to its effectiveness in improving comprehension, engagement, and problem-solving skills. The technology's ability to create realistic virtual scenarios closely mirroring actual assembly challenges provides a bridge between theory and practical application, enriching the educational experience. The positive alignment with the curriculum and the clarity of instructions affirm the seamless integration of augmented/virtual reality into traditional teaching methods.

Looking ahead, the feedback not only validates the current success of this pedagogical approach but also signals avenues for future development. Suggestions for expanding the variety of virtual scenarios and incorporating more advanced challenges reflect a readiness among students for deeper, more diverse experiences. As technology continues to evolve, there is a clear opportunity to further refine and expand the use of augmented/virtual reality in engineering education, fostering collaboration and ensuring that graduates are well-equipped with the practical skills needed in the rapidly advancing field of robotics and automation.

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