PAPER

# Towards a New Robotics Training Model: Improving Access to Robotics Education for Architecture Students

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**Technological advancements in robotics and automation are poised to disrupt the Architecture, Engineering, and Construction (AEC) industry sector but robotics training within these fields has historically faced issues of high cost, limited accessibility, and narrow demographic representation. Architecture students are typically at a disadvantage compared to their peers in engineering disciplines due to a historic and ongoing lack of access to robotic tools and established training opportunities tailored to their educational needs. Women and minority students often face even greater obstacles to access due to the scarcity of robotics training options in a male-dominated field that tends to lack diversity. This paper examines how emerging artificial intelligence (AI) and immersive technologies can help to transform robotics education to be more equitable, adaptive, and scalable. It begins by outlining current limitations in traditional training methods, which rely on in-person workshops with proprietary systems. Next, it explores the educational affordances and ethical risks of incorporating AI for personalized learning. The paper then discusses how virtual reality (VR) and augmented reality (AR) can be employed to create more accessible and engaging robotics curricula, underscoring that these same advanced technologies may also introduce potential biases if training data is not sufficiently diverse. The paper describes ongoing initiatives by an interdisciplinary research team led by architecture faculty at a coalition of public majority-minority research universities to help improve access to training and representation in the field of robotics. It describes three projects funded by the National Science Foundation that leverage VR, AR, and AI to create a more inclusive robotics training tailored for learners from multicultural and minoritized backgrounds. These projects collect learner data and real-time performance metrics to support the design of adaptive learning systems that can enhance learning outcomes for a diverse pool of learners. The paper addresses the pressing imperative to re-envision existing technical training models by leveraging AI and immersive technologies to foster enhanced representation and improve access to robotics education.**

## INTRODUCTION

Today, we are confronted with existential challenges. The convergence of significant impacts stemming from factors such as global warming, rising social disparities, and economic inequalities exacerbated by automation and AI technologies characterizes our current period and the foreseeable future. In response to these challenges, it is imperative to critically reassess established academic disciplines and professions, considering their historical origins in structures of power, inherent biases, and their effects on labor relations and the workforce. Fields like architecture, engineering, and construction (AEC), which play a pivotal role in shaping our built environments and have deep-rooted connections to issues of discrimination, inequality, and bias, require urgent and thorough reevaluation.

As Artificial Intelligence (AI) and automation disrupt labor markets, it becomes even more crucial to reimagine our educational frameworks. Our educational systems must not only impart technical skills but also equip individuals in AEC with the capacity and awareness needed to navigate these crises effectively. Education should empower diverse communities to influence the trajectory of AI and emerging technologies, ensuring that they actively shape these developments rather than being passive recipients or marginalized by them. To achieve this, it is essential to center critical perspectives that illuminate the intricate power dynamics within AEC fields, which underlie labor, technology, and societal structures. Our educational frameworks must be designed to empower learners from diverse backgrounds to ethically apply automation and robotics for the betterment of the environment, society, and the economy.

Given this context, it is evident that the current training models and programs for robotic programming and operation must undergo revision, addressing several limitations that impede their scalability, ease of distribution, and inclusiveness. One of the primary challenges is cost, as specialized training programs often come with a hefty price tag, thereby creating barriers to entry for individuals and organizations with limited resources.[1] This financial obstacle perpetuates a cycle wherein only well-funded entities can afford to develop expertise, resulting in the concentration of skills and capabilities among a privileged few.

Additionally, traditional training models frequently rely on resource-intensive approaches, such as in-person workshops and specialized equipment. These methods are challenging to scale effectively in response to the growing demand for robotics skills. Moreover, many existing programs are tailored explicitly to the technologies of specific manufacturers, limiting the adaptability of the training. This specialization leads to a cohesive skills landscape where individuals are proficient in operating systems from one manufacturer but must be equipped to adapt to a competitor's hardware and software. The lack of interoperability in such training programs could potentially stifle innovation and restrict the agility required for workers to adapt to the rapidly evolving technological landscapes.

This paper commences with an exploration of the prevailing state of robotics training in the AEC sector, with a particular emphasis on the challenges that define this field. It subsequently delves into recent technological advancements in AI and immersive technologies in the context of education, including an examination of both the advantages and the potential risks or drawbacks introduced when integrating AI into educational systems. Lastly, the paper outlines the initiatives undertaken by the [Anonymized] Lab at [Anonymized] University in collaboration with research partners at a coalition of public minority serving institutions. It provides insights into two ongoing projects, each strategically designed to address and resolve challenges in AI-powered robotic training. These projects represent practical responses to the issues identified earlier in this paper, with the overarching goal of advancing the field by offering actionable solutions.

## CURRENT ROBOTICS TRAINING PRACTICES: ACCESS, STANDARDIZATION, AND PEDAGOGY

The Architecture and Building Industry is transforming, primarily fueled by robotic automation and Artificial Intelligence integration. These technologies are fundamentally changing traditional practices in designing, planning, and constructing built environments. These shifts introduce a host of challenges to which professionals must swiftly adapt. Given these circumstances, practical training is critical in preparing the future workforce to navigate and leverage these advances.

Despite the growing demand for roboticists, training programs still need to be expanded in scale and scope.[2] Industrial robotics training is often conducted in specialized classrooms at a few on-site facilities, making it prohibitive for most people to access without sponsorship and support. A typical student has to take time off from work, travel to a specialized training facility, and stay in a hotel while completing their training. To accommodate this common situation, training is typically condensed or intensive, designed to be delivered as quickly as feasible. This method does not necessarily support different types of learners who may experience more effective learning using an alternative modality or at a different pace. Although effective, traditional classroom setups for teaching robotics often demand a low student-to-teacher ratio and access to specialized equipment.[3] This bottleneck hinders access to training for the vast majority of workers who will need to upskill in order to remain competitive in the labor market.

Before attending robotics training workshops, learners often begin with text or proprietary manuals that focus on how to work with a specific brand or type of equipment. Training sessions include lectures, live demonstrations, and supervised hands-on practice with a training robot. Cohort sizes are often small, and training follows patterns associated with traditional classrooms or workshop settings. Learning is geared toward proprietary equipment, systems, interfaces, and software with little attention to the transferability of knowledge to other brands or types of robotic tools and systems. Since most robot manufacturers use different hardware and software configurations, more standardization is needed in control interfaces, nomenclature, and programming procedures. For this reason, training and proficiency in working with one type of robot do not easily translate to competency with those produced by other manufacturers.

Most training is oriented towards the commissioning, calibration, and maintenance of equipment as well as typical manufacturing or material handling procedures using proprietary equipment and software. Training content is typically designed to support students learning, reproducing, and mastering the correct concepts and techniques while avoiding spontaneous decision-making in order to minimize misconceptions, mistakes, and the development of poor habits. Knowledge or mastery in this learning model is conceived as knowing the singular correct response to a particular problem or the correct next step in a predetermined procedure or sequence. This approach anticipates learned responses known by the learner, having been programmed by the instructor.[4]

In most training, there is little focus on general knowledge, concepts, and transferable strategies for working creatively to address common issues one might encounter working with other types of robots in different procedures, scenarios, or conditions. Emphasis on developing procedural skills tailored to specific platforms has come at the expense of fostering a holistic conceptual understanding, systems thinking, creativity and problem-solving that enable adaptability across contexts. Technical instruction has been typically prioritized without adequate incorporation of socio-ethical considerations essential for the responsible development and deployment of automation technologies.

In recent years, developments in Artificial Intelligence, Augmented Reality (AR), and Virtual Reality (VR) have facilitated the creation of immersive and interactive learning environments. Similarly, the rise of machine learning and big data analytics allows for more nuanced, real-time assessments of student performance, thereby enabling personalized learning pathways. The integration of these technologies holds the promise of making learning more adaptive and scalable, thereby transforming education for greater inclusivity and democratizing access for all learners. However, as we begin working toward transforming robotics education, our expectations regarding learning content and objectives must be realigned for technical competency, critical thinking, and ethical application. Educating the next generation demands integrating technical depth with humanistic breadth, equipping learners to align innovations with shared values. We must view robotics knowledge not as fixed procedures within proprietary systems but as a means to collaboratively reshape automation technology in service of ecological sustainability, social equity, and human dignity.

## EMERGING TECHNOLOGIES FOR ENHANCED ROBOTICS TRAINING

*The Affordances and Pitfalls of AI-Driven Learning:* Understanding the mental, psychological, and social processes involved in the learning process can help us better serve students' varied learning needs. However, this has historically been a complex endeavor. This complexity arises from the need to accommodate a range of factors, including diverse backgrounds, differing cognitive capabilities, and the imperative for immediate, context-sensitive feedback. These multi-dimensional variables often interact in perplexing ways, thus rendering the design of a universal educational approach for robotics highly challenging.

Emerging advancements in AI and computational technologies are heralding transformative approaches to addressing these complex educational challenge.[5] Recent strides in logical reasoning, big data, predictive analytics, and natural language processing enable the development of Intelligent Adaptive Learning Systems.[6,7] These systems aim to transcend the limitations of traditional pedagogical methods by offering personalized instruction. These technologies enable the quantification of student behavior and performance, providing previously elusive insights. Data-driven algorithmic decisions can then effectively guide students through training modules, increasing the probability of successful learning outcomes. This level of personalization offers considerable benefits, including increased educational efficacy by catering to individual students' diverse learning paces and trajectories. Thus, AI-driven educational models not only stand to improve learning outcomes but also aim to democratize access to high-quality education, offering more significant equity for learners from various backgrounds and cognitive abilities.

Nonetheless, the integration of AI into educational systems is fraught with ethical complications. Of paramount concern is the risk of algorithmic bias originating from training datasets that are skewed or unrepresentative. [8,9,10,11,12,13,14,15] These biases can and often do arise inadvertently through the natural process of training AI systems on data from a homogeneous group of individuals. This can lead to a narrow or distorted understanding of learning behaviors and needs, undermining the efficacy and fairness of AI-driven educational solutions. Researchers emphasize the potential for bias to arise even in well-intentioned systems if the training data does not adequately reflect diverse populations. Such bias may result in inaccurate or unfair educational assessments, eroding the trustworthiness of AI-driven educational systems.

To mitigate the risk of AI bias, educators and researchers are responsible for proactively addressing these ethical considerations. This begins with the thoughtful curation of training datasets representative of the diverse populations these educational systems aim to serve. Furthermore, continuous monitoring and auditing of algorithmic decision-making are crucial for identifying and correcting inadvertent biases that may emerge over time. Educators can also incorporate explainability and transparency features into AI systems, allowing a clearer understanding of how educational assessments are generated. In this way, end-users are empowered to question and scrutinize the AI's decisions, enhancing system accountability.

*Spatial and Immersive Technologies for Enhanced Learning:* Spatial and immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR), are becoming a leading frontier in computing. They are also revolutionizing the fields of training and education.[16,17] These technologies enable the creation of computer-generated simulations that greatly enhance the training experience, creating a more engaging and enriched learning environment.[18,19] Research has shown that simulated environments are highly conducive to training and learning assessments, providing a safe and cost-effective space for practical rehearsals.[20]

In the context of robotics training, spatial and immersive technologies like VR and AR offer unique benefits. VR can provide a safe and risk-free training environment, allowing students to engage in simulations before working with real robotic systems. Simulated equipment and environments reduce the time and cost associated with training by increasing familiarity with robotic setups, operations, and scenarios.[21] Conversely, AR can offer supplementary feedback and information when students are ready to interact with real-world robots. Overlaying situational data and simulations in AR can deliver real-time guidance and feedback, enhancing the learning process.[22] When combined with AI technologies that actively monitor and respond to the learner's actions in a changing physical environment, this type of information can act as a form of virtual coaching.

AR and VR technologies can be strategically integrated at different stages of training to optimize the learning process. Furthermore, these technologies offer two significant advantages for scalability. Firstly, their virtual nature allows for easy updates and the inclusion of new training scenarios, ensuring that the content remains current and relevant.[23] This is particularly valuable in the field of rapidly evolving robotic automation, where the costs and logistical challenges of constantly updating physical training setups can be prohibitive. Secondly, these technologies facilitate the dissemination of training materials, enabling broader distribution beyond traditional workshops and classrooms. As a result, AI and immersive technologies have the potential to democratize specialized training, making it more accessible to a wider audience while circumventing the logistical and financial constraints faced by both trainers and trainees.

## NARROW REPRESENTATION AND ITS PERVASIVE EFFECTS

While the discussion has thus far focused on the technological aspects of developing effective robotics training, it is crucial to confront the broader issues of equity and access. Like other STEM domains, the field of robotics has historically been characterized by a striking lack of diversity.[23] Recent findings indicate that women represent a scant 16% of individuals in engineering and robotics roles.[24] Meanwhile, according to the US Bureau of Labor Statistics, the percentage of women in the construction industry is only 10%.[25] Furthermore, while Hispanic workers make up more than 30% of the construction workforce, Black workers make up only 5%. These concerns are magnified when considering ethnic diversity within the STEM workforce.[26] Data from the National Center for Science and Engineering Statistics in 2023 reveals that Hispanic and Black workers comprise only 15% and 9% of the total STEM workforce, respectively. This limited diversity has far-reaching implications, affecting not only individual opportunities but also the sector's collective intellectual and creative output.

This narrow representation has multi-layered consequences in the field of robotics. Curriculum and training materials, predominantly shaped by a limited demographic, often need more comprehensive perspectives a more diverse group would contribute. This type of environment risks becoming an echo chamber, serving to fortify existing biases and stifling intellectual diversity. As observed in various other domains,[27] individuals from different backgrounds offer unique approaches to problem identification, analysis, and resolution. If opening the field of robotics to an increasingly diverse pool of people is to be successful, improving representation in the development of training tools is a critical first step.

As previously discussed, additional layers of complexity and associated risks emerge when incorporating advanced technologies such as artificial intelligence for personalized training. A primary concern revolves around the quality and diversity of training data employed in creating AI models. If these datasets originate from a restricted demographic, the AI systems can cultivate and disseminate biases inherent to that particular group.[28] Such biases may have detrimental implications for personalized learning experiences, notably affecting underrepresented or marginalized communities.

The impact of such limitations extends beyond individual educational programs or training sessions. Bias can be systemically ingrained into the underpinnings of the educational, professional, and research systems themselves, thereby compromising the effectiveness of the training tools that can be conceived, developed, and implemented. This subtle type of unconscious bias has a knock-on effect that limits diversity of thought and innovation, thereby reinforcing the systems and structures responsible for creating bias and a lack of representation in the first place.[29] This

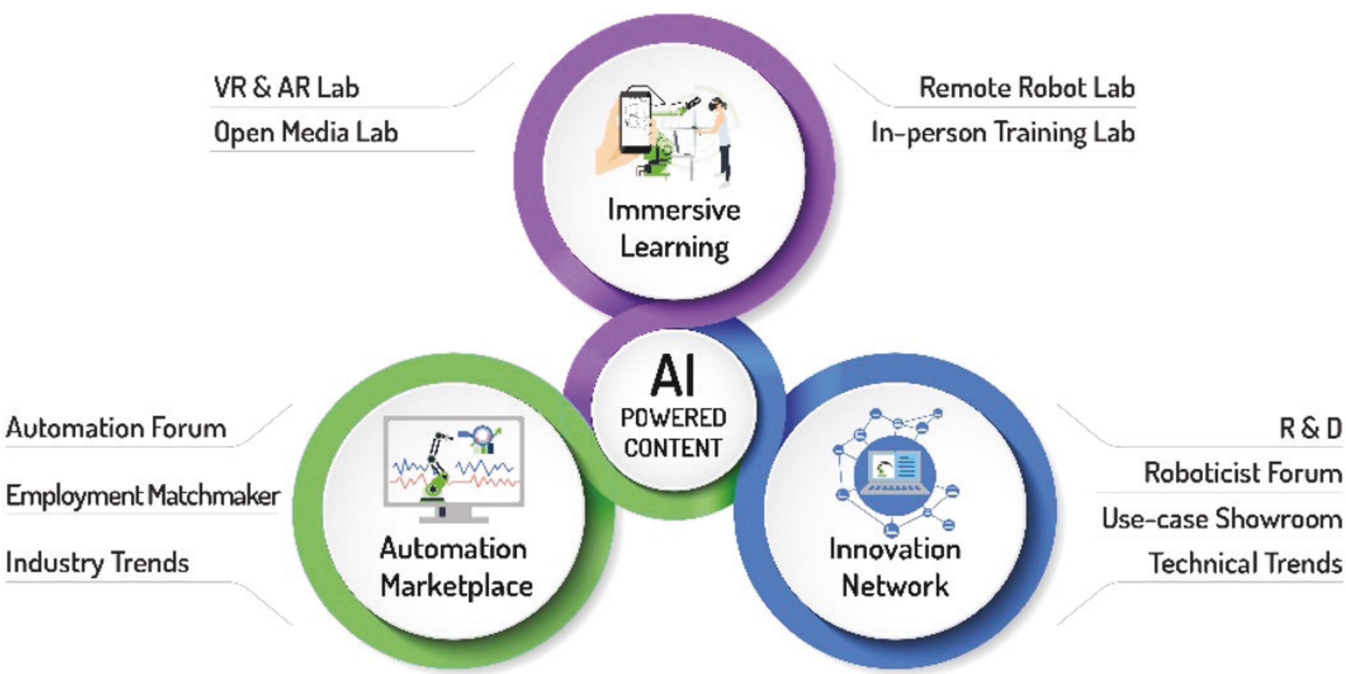


Figure 1. Overall structure of the Robotics Academy.

leads to a situation in which the potential for novel applications of robotics technologies is reduced, and the entire field is less creative, less competitive, and less economically productive.

## IN PURSUIT OF EQUITABLE OUTCOMES

In an effort to address training challenges, this section of the paper discusses initiatives undertaken by the [Anonymized] Lab at [Anonymized University]. Housed within the School of Architecture, the Lab's research agenda is structured around three synergistic pillars: Innovative Learning Platforms, Spatial Computing and Representation, and Emergent Materials and Digital Fabrication.

[Anonymized University]'s distinctive status as one of the largest public Minority Serving Institutions in the country offers the Lab a unique environment in which to shape its research agenda. The Lab is also situated in a city where the majority of residents speak English as a second language. This contextual backdrop has shaped the Lab's research agenda, resulting in a broad portfolio of projects aimed at addressing the pressing need to develop training tools and research projects tailored to meet the needs of a multicultural and multilingual demographic.

The leadership configuration of the [Anonymized] Lab plays a pivotal role in shaping its commitment to diversity and inclusion. Led by two minority women with backgrounds in architecture, education, structural engineering, computational design, and media arts, the Lab has consistently prioritized inclusivity, as evidenced by the composition of its student and research assistant cohort. Over the past three years, the Lab has maintained an average women representation of 75% among its students and research assistants. This demographic makeup underscores the Lab's ongoing efforts to foster a diverse and inclusive research environment.

In a further commitment to leveraging the diversity of the student body, the [Anonymized] Lab has developed projects that incorporate state-of-the-art spatial and immersive technologies for enhanced robotics training and employ AI to develop personalized learning environments with the potential for more significant impacts on the AEC industry. These projects are not merely technological exercises; instead, they aim to ensure that the design and evaluation of immersive learning technologies accommodate the diverse learning needs of the student body. The following three sections provide overviews of three related projects at the Lab. These projects serve as case studies illustrating how emerging technologies could be leveraged to foster greater inclusivity in robotic training.

## 1) ROBOTICS ACADEMY

In 2019, researchers at the [Anonymized] Lab initiated a one-year project funded by the National Science Foundation (NSF) Convergence Accelerator (C-ACCEL) Program. Their goal was to plan and design a comprehensive robotics training program called the Robotic Academy. This planning phase involved a thorough assessment of industry-specific training needs, which was conducted through expert interviews and focus group studies. This groundwork served as the foundation for developing the entire training program, emphasizing the importance of using both in-person and virtual delivery methods. The program aimed to disseminate knowledge in industrial and small robotics.[30]


Figure 2. Scene from the VR learning prototype demonstrating how the command panel corresponds to a physical teach pendant in real world.

The Robotic Academy was conceptualized as a cloud-based resource intended to benefit the Architecture, Engineering, and Construction (AEC) workforce. The overarching goals included expanding access to training, creating a community of AEC roboticists, and fostering connections between employers and roboticists to address the industry's demand for highly skilled individuals. The proposed framework encompassed three key components: 1. Immersive Learning: This component focuses on an AI-powered, customizable curriculum delivered through

Augmented Reality (AR) and Virtual Reality (VR). 2) Open Knowledge Network (OKN): This component aimed to facilitate knowledge sharing and technical problem-solving by establishing a centralized hub for researchers, professionals, and students to exchange information. 3) Automation Marketplace: This component served as a platform for adaptive matchmaking, connecting entrepreneurs, employers, and employees for job opportunities.

Following the completion of this plan, the research team concentrated on developing a "proof of concept" for the Immersive Learning Branch. User testing revealed that VR was well-suited

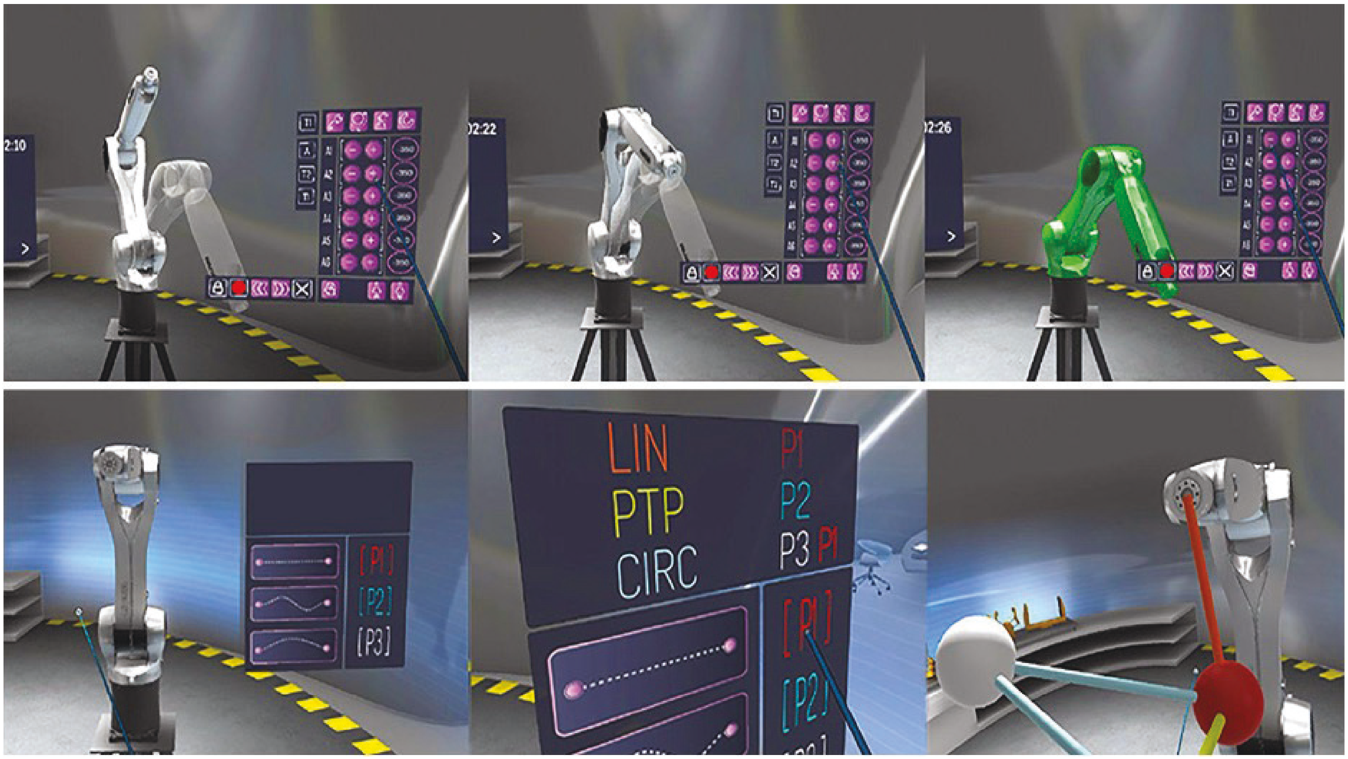


Figure 3. Scenes from the VR learning prototype demonstrate how the curriculum addresses the concept of alternate coordinate systems and helps learners to build skills in jogging the robot. This task challenges students to match the pose of the *ghosted* robotic arm using Axis-Specific and World-Specific motion types - the arm turns green when the poses match.

for introductory and safety topics due to its immersive nature, while AR was more appropriate for advanced subjects that required hands-on interaction with robot*s.* [31]

These findings were influenced by the limitations of existing Head-Mounted Displays (HMDs), with an understanding that the future of immersive media was likely to merge VR and AR capabilities in all HMDs.[32]

The team integrated a rudimentary adaptive learning system into the prototype to test the introductory curriculum content and delivery. The learning environment, designed for HTC Vive Eye Pro HMD using the Unity game engine, simulated a large industrial robotics training facility with dedicated work cells and various training robots for each lesson. Participants were encouraged to navigate the training environment at their own pace, engaging with industrial robots, safety videos, and interactive demonstrations on robotic anatomy and terminology.

The final prototype marked a significant milestone, confirming the feasibility of the team's approach and paving the way for future projects to advance robotics training.

### 2) AN INTELLIGENT IMMERSIVE ENVIRONMENT FOR LEARNING ROBOTICS

Building upon the research and development work conducted in the section 5.1 project, the team secured additional support from the NSF's [Anonymized Program] to launch a new initiative focused on creating an intelligent and immersive environment for learning robotics. This project leverages Machine Learning and Natural Language Processing algorithms to craft a personalized learning experience within a VR setting, building upon the previously developed prototype.

The curriculum for this project comprises six core modules, ranging from foundational topics such as workplace safety and robotic anatomy to more advanced subjects like calibrating and programming industrial robotic arms. These modules are presented as a learning game designed to enhance engagement by allowing students to practice skills and receive performance-based scores. The adaptive learning system gathers a comprehensive set of metrics from the learner's interactions within the VR environment to achieve the project's personalization objectives. This includes data such as the time spent on activities, the number of attempts made, verbal responses to system-generated queries, and performance results from quizzes and tasks. Additionally, the system considers information from students' profiles, including their backgrounds and skill levels. The system tailors the training experience by combining performance data points, enabling a more nuanced and adaptive learning path that aligns with each individual's needs and progress.

This project addresses a crucial research gap by integrating learning systems with immersive virtual environments to create an adaptive learning experience. While previous research has explored these domains separately, merging these elements to


Figure 4. A visual representation of a student engaging with the VR Interface during lesson selection.

construct a robust personalized learning system represents a novel endeavor. Testing this AI-powered approach within an immersive VR curriculum demonstrates an advanced application of adaptive learning. Furthermore, the curriculum's development by a diverse team and its extensive testing with underrepresented participants safeguard against inherent biases and provide a rich dataset for refining the adaptive learning system.

### 3) AUGMENTED LEARNING FOR ENVIRONMENTAL ROBOTICS TECHNOLOGIES (ALERT)

This project, funded by the NSF's [Anonymized Program Focused on Undergraduate STEM Education], focuses on augmented learning for environmental robotics technologies. This project is designed as an educational tool to build expertise in small robotics, specifically targeting environmental data collection, analysis, and visualization. The project aims to provide a specialized curriculum in environmental robotics education, leveraging AR as the primary mode of content delivery. The project offers an immersive and interactive learning experience using AR that facilitates a deeper understanding of environmental data and robotics applications in real-world settings.

Using the project's adaptive learning system, students engage in guided learning activities while wearing an AR headset to work with various "parts kits." In some cases, kits are physical components that must be assembled in a specific way. In other instances, they are snippets of code or blocks of data that can be plugged into one another in various ways to perform actions or display information. The interactive nature of handling physical components and viewing lines of code and blocks of data with on-demand informational overlays allows learners to explore how the components and data modules can be assembled to create a robot for collecting and viewing data from the environment.

The curriculum is structured into three modules, including foundational concepts through customized online lessons and assessments, applied learning tasks delivering hands-on project development, and testing in a face-to-face classroom using augmented reality headsets. Students assemble and program environmental monitoring devices tailored to their interests. The data analysis module teaches interactive techniques to understand and communicate insights from the collected data through immersive data visualizations. This multifaceted curriculum ensures students gain theoretical knowledge, practical skills, and data literacy.

In this project, the data collection for personalizing the learning experience employs a range of metrics. First, the student profile data captures background information and pre-existing skill levels. This sets the initial context for tailoring the curriculum to individual needs. Second, student performance in quick quiz questions provides real-time assessments that are immediate indicators of comprehension and engagement. This allows the adaptive system to adjust the content or difficulty levels instantly. Third, eye gaze information is collected as biometric data, providing insights into the learner's focus and cognitive load.[33, 34] This nuanced data can indicate whether a student is engaged,

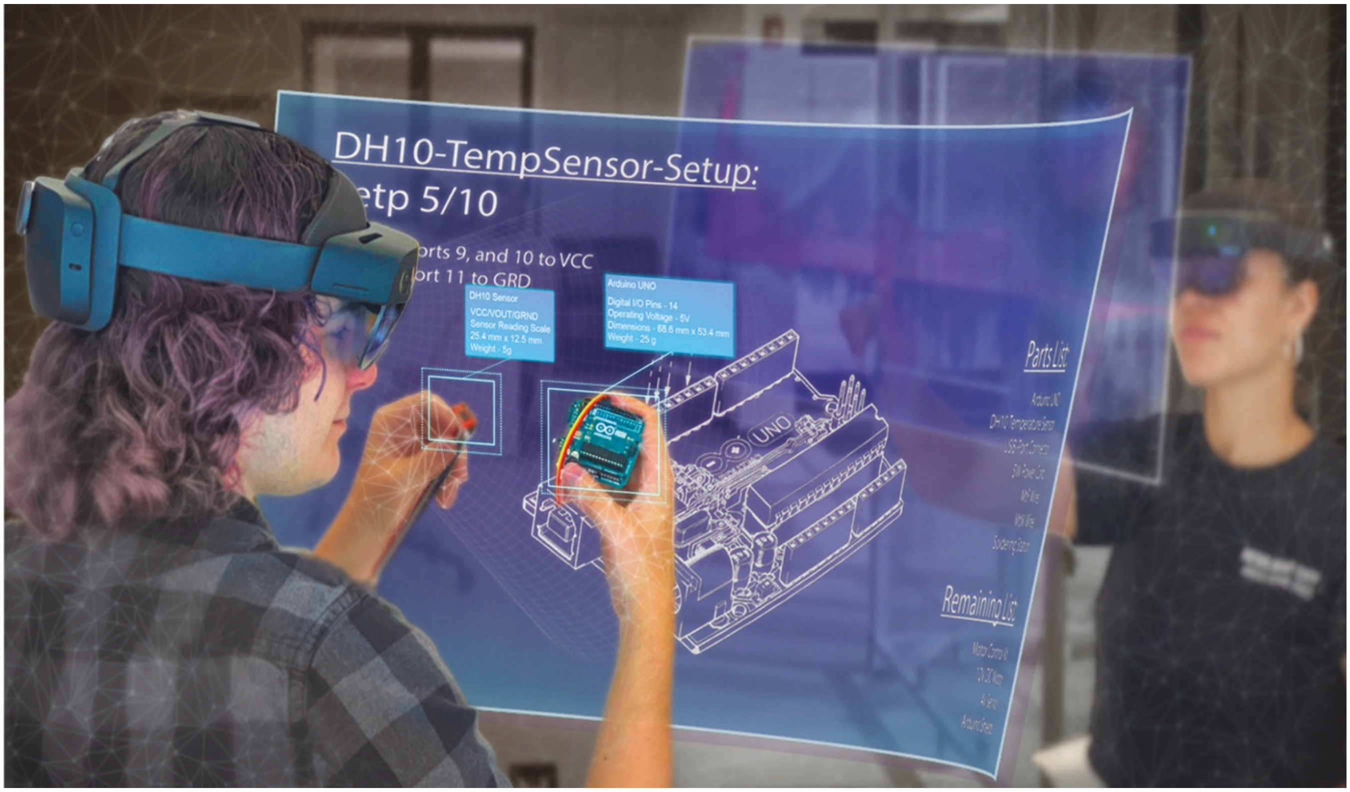


Figure 4. A visual representation of a student engaging with the project's VR Interface during lesson selection..

providing insights into the learner's focus and cognitive load.[33,34] This nuanced data can indicate whether a student is engaged, confused, or requires additional support, enabling a more dynamically responsive learning experience. Collectively, these data sources contribute to creating an exceptionally tailored educational experience designed to optimize learning outcomes for each student.

Like the other two discussed projects, the project also leverages technology to foster inclusivity and the needs of diverse learners. Embracing Augmented Reality and adaptive learning mechanisms, it intentionally creates a learning environment that transcends traditional barriers, accommodating many learning styles and backgrounds. With this project, the importance of creating training platforms that embrace diversity for optimal learning outcomes is underscored, echoing the broader narrative of inclusion within the ever-evolving realm of AEC.

## CONCLUSION

The need for diversity and accessibility in robotics training is a pressing concern that demands immediate attention. Historically, robotics education has been constrained by limited resources and location-specific requirements, limiting its accessibility to a broader range of students. These constraints perpetuate inequality, particularly in in-stitutions like [Anonymized University]. However, emerging technologies such as AI, VR, and AR, when used alongside ethical approaches and insights from learning science, hold transformative potential.

This paper has examined projects that harness cutting-edge technologies to promote diversity and inclusion in robotics education within the field of Architecture, Engineering, and Construction (AEC) at [Anonymized University]. By utilizing AI-powered adaptive algorithms that cater to diverse learner data and styles, these pro-jects represent both technological progress and the promotion of social equity. Tailored to accommodate a varied student body with distinct educational backgrounds and needs, these initiatives aim to level the educational playing field by providing personalized and empowering learning experiences.

The unique environment of [Anonymized University] provides an ideal testing ground for validating and refining these systems, given its diversity and representation of broader educational challenges. The insights gained from these projects enhance pedagogical approaches within the university and offer valuable lessons for addressing diversity and inclusion challenges in robotics education on a larger scale in the AEC industry.

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**Keywords:** Insert 3-5 keywords or short phrases for your paper separated by commas. Use 06_MainBody... Paragraph Style.

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