Robotics Academy: An Immersive Learning Game for Training Industrial Roboticists

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Abstract

Emerging technologies, including artificial intelligence (AI), robotics, digital fabrication, spatial computing, and immersive media such as Augmented Reality (AR) and Virtual Reality (VR), are changing the employment landscape across a broad range of industries. It is anticipated that these technologies will enhance research and innovation, increase productivity, and spur new types of occupations and entrepreneurship. In the architecture, engineering, and construction (AEC) fields, automated building design with advanced software facilitating mass customization will change how buildings are designed. Robotics and automation, particularly in prefabrication and large-scale 3D printing of buildings is expected to change how buildings are built. Automation technology will also transform how work is managed and conducted in the AEC sector. Therefore, it is imperative to prepare students for future changes brought by automation.

The Robotics Academy project is a cloud-based training platform designed to support AEC students in learning industrial robotics. This platform uses advances in cloud computing, VR, and learning games to create a personalized and engaging experience for developing programming and robotics operations skills. The Robotics Academy's immersive learning environment aims to offer a solution for teaching robotics in a safe simulated workspace that delivers creative training while minimizing risk. This virtual modality also allows the students to acquire knowledge remotely and without relying on accessing a robotics lab.

This paper outlines the process of designing the Robotics Academy's pedagogical approach, its curriculum development, and its delivery method as a VR application. The paper will also describe plans for its future development as a fully customizable and immersive learning game for training students for future jobs in industrial robotics.

Keywords: Virtual Reality, Learning Game, Pedagogy, Robotics Education, Robotics Curriculum, Robotics Training, Automation.

Introduction

Emerging technologies, including Artificial Intelligence (AI), information technology, robotics, digital fabrication, spatial computing, and immersive media including both Augmented Reality (AR) and Virtual Reality (VR), are rapidly changing innovation and communication in all industries, including building and construction technology research and production. It is expected that these technologies will increase productivity, fuel economic growth, contribute to sustainable construction, spur new types of occupations and entrepreneurship, and free people from working mundane jobs (Manyika et al. 2017; Bugmann et al 2011).

In the Architecture, Engineering, and Construction (AEC) fields, automated building design with advanced software, mass customization of building components with robotics, and large-scale 3D printing of buildings are projected to grow steadily. According to The World Economic Forum, increasing demand for manufacturing with advanced materials will become a new source for jobs. The report also states that these technologies could be strong drivers of employment growth in the AEC job market. They foresee that manufacturing will transform into a technologically advanced sector, where highly skilled architects and engineers will make the Industrial Internet of Things (IoT) a reality (WEF, 2016). Thus, preparing architects for robotics automation and digital fabrication is imperative for the discipline and the profession.

Advanced technologies are also changing the learning and training landscapes. Achievements in game design and immersive environments, self-adaptive, data-driven, and autonomous systems used for virtual training in the medical and industrial fields, are examples of what is possible with these technologies (Dac-Nhuong, et al. 2018). Our project, the Robotics Academy, is inspired by these technologies with an aim of providing an enhanced learning venue for industrial robotic operations and processes.

The Robotics Academy project is a cloud-based training platform designed to support AEC students in learning industrial robotics. The Robotics Academy is composed of three complementary branches for delivering a complete training program which includes: 1) a Virtual Learning Environment, providing a VR curriculum; 2) , an Innovation Network, providing an AI powered roboticists forum and, 3) an Automation Marketplace, which is an employment matchmaker connecting newly skilled students with job opportunities.

This paper will focus on the design and development of the Virtual Learning Environment and reports on the completion of its prototype. It highlights our pedagogical approach for curriculum development and its delivery method as an immersive game. This work has been developed with the support of a grant from the National Science Foundation (NSF). The funding has provided the resources to research, plan, and produce a prototype for the project. The project has involved a group of interdisciplinary faculty and researchers from architecture, computer science, engineering, and construction.

Project Approach

To understand the future training needs of the industry and gaining a better understanding of how to prepare students for robotics automation, we conducted a series of interviews with architects, automation engineers, software developers, roboticists, educators, and system integrators, as well as product design specialists in the AEC fields.

Analyzing interviews revealed several findings. First, that new applications and use cases for robotics automation, particularly industrial robotic arms are rapidly increasing because of their versatility and efficiency. The adoption of robotics in the building industry is creating new jobs, entirely new job classes, and opportunities for entrepreneurship. However there are not enough skilled people in the country and some employers are reaching outside the US to hire robotics specialists.

Our second finding is that the materials for training robotics are scarce, costly, and difficult to access. These contents are often intended for engineers not architects, which creates a significant barrier for entry. Most interviewees reported that they had to learn on the job through trial and error or used online sources and manufacturer’s manuals to run robotic arms, which they found very inefficient and dull. They also expressed the need for interaction with a robot as an important part of their learning process. Finally, a big hurdle in the learning process is the lack of a standard robotic design and manufacturing process, therefore the knowledge pool is scattered and not comprehensive.

In the next step of our research process, we held an Industry Summit with representatives of the foremost AEC firms in the Southeast United States, two of the nation's largest housing developers and builders, and an industry-leading robotic company. The Summit revealed similar concerns regarding the growing shortage of skilled workers in the AEC industry with reports of low productivity and increasing demand for skilled labor in the building industry. The experts argued that a transition to automated design, engineering, and construction will have severely disruptive impacts on the AEC sector. At the same time, this situation offers a great potential for increased productivity that will likely lead to increased demand for skilled professionals in robotic programming and factory-based prefabrication.

The design of the Robotics Academy was informed by our understanding of the impacts of automation on the AEC industry and its future employment needs. In addition, we leveraged recent technological advances in interactive and game-based learning to enhance the learning experience. We approached the project by considering what would be an appropriate curriculum for learning a highly technical skill through interaction with robotics arms, and how the curriculum delivery could support that. Our aim was to provide broad access to learning resources for a large pool of potential students, particularly in architecture and building construction disciplines.

We recognized that a key objective of the project should be to develop a learning platform that could be distributed online with truly interactive content. Thus a learning game using immersive technologies emerged as an effective approach to teach a complex topic in an interactive and visual way that can appeal to a broader range of students. At the same time, immersive technology with simulated robotic tools offered the added benefit of a low cost and safe training modality that approximated a responsive, real-world environment.

Game Environment for Learning

Learning Games or Serious Games designed for a primary purpose other than pure entertainment, have been receiving growing attention for use in education. Research shows that these games provide a learner-centered approach that encourages active participation and learning through exploration (Checa & Bustillo, 2020).

Games have three main features that can promote learning: first, *Immersion* contextualizes the learning experience. Immersion is often achieved with an engaging story or plot in a simulated environment to help focus and direct attention to learning objectives. The Robotics Academy curriculum is designed with a series of fully immersive scenario-driven lessons where learner interactions with virtual robots, end of arm tools, and other objects are completely simulated. We have designed a series of virtual workspaces modeled on the typical settings one might find in a manufacturing or specialized fabrication facility. Robots in the learning environment can be controlled in much the same way they are in a real-world setting. Conceptual or foundational knowledge is built into each scenario so that learning is situated within active engagement. As students interact with simulated robots and control systems, they learn about typical robotic configurations, safety devices, and protocols. This format offers a secure space to train roboticists and conduct exercises that would otherwise be risky and costly in real life.

Second, *Interactivity* has been extensively studied and evaluated in the field of Human-Computer-Interaction. Interactivity is an integral part of educational games as it facilitates experimentation and exploration by encouraging learners to engage (Zhang et al. 2019 and Hollender et al. 2010). Interactivity is supported by immediate, individualized, and detailed feedback to enhance learning outcomes. At a fundamental level, the learning environment is designed to be responsive to the learner's input. All actions that a learner initiates in the learning environment are fully simulated to promote learning by doing - including learning from mistakes.

Third, *Motivation* is a feature of immersive games that promotes learning. Motivation can lead to increased attention, depth of involvement, task persistence, and cognitive flow (Karampiperis & Sampson, 2004). Considering that lack of motivation is one of the significant challenges facing educators, building motivation within games can significantly enhance the learning process. In the Robotics Academy, motivation is fostered with a reward system including encouragement, points, rankings, and badges that promote healthy competition and enhance learner engagement. The curriculum structure appeals to learners with a series of badges that can be used when applying for jobs or promotions.

Curriculum Design for Virtual Learning Environment

In developing an approach to the Robotics Academy curriculum, we studied existing AEC and robotics courses, interviewed academics and professionals, consulted with STEM curriculum developers and evaluators, and worked with AI experts. We recognized from our interviews that the curriculum needed to offer flexibility for a variety of learners and jobs. The standard format of lectures, day-long workshops, and textbook chapter modules was insufficient to the needs of our target group. At the same time, we recognized that a lack of standardization among robotic hardware and software interfaces required a concept-based approach to learning.

The structural hierarchy of the Robotics Academy curriculum consists of badges, courses, lessons, and modules that can be assembled in a variety of different ways. The curriculum approaches robotics in a comprehensive framework that includes introductory to advanced concepts as fundamental units in a highly granular armature that can be adapted and re-ordered for a broad range of learner competencies and learner objectives. Unlike many other training systems, our curriculum has the capacity to customize the learning sequence and content range for each individual learner, and it uses interactive content to reinforce both self-reported and performance-measured competencies.

Fig. 1. Scene from the VR learning prototype demonstrating lesson selection process.

Our curriculum includes lessons on the Fundamentals of Robotics Operation and Safety, Robotic Movement, Robotic Simulation, End of Arm Tooling, and Hardware Integration. The following section describes three example lessons from these content areas:

Robotic Anatomy and Basic Operations: in this lesson a beginner is presented with a series of interactive simulations describing the robotic anatomy and nomenclature. In the next step, the learner is prompted to identify each component and its function with a pointer or audio input. Once the student understands the basic robotic anatomy, the system will present a simulation of robotics movements. The learner is then guided through the fundamentals of robotic programming with a series of task-oriented activities for mimicking the movement of an animated robotic arm using various motion types. In the process, the learner is challenged to instrumentalize prior knowledge of basic concepts, safety, and logical order of operations.

Introduction to End of Arm Tools: in this lesson the student learns the basics of end of arm tooling by using a gripper to move objects from one location to another. The learner is guided through a series of steps to complete a simple “pick and place” task. During this lesson, the learner identifies several common end of arm tools, and learns how to mount and connect them to power, data, pneumatic, and other relevant systems from the robot to the end effector. The students are challenged to use their knowledge from the previous lesson to program the robot and actuate the end of the arm tool. In order to proceed to the next lesson, the student must demonstrate knowledge of fundamental concepts and safety protocols while performing the task. When the student encounters an issue, error, or misstep, they are guided to a solution with on-screen direction. Students are guided through a refresher scenario if the issue persists.

Robotic Simulation: this lesson lays out the common procedures for preparing how to use a robotic arm for a new task. The student learns how to use software to simulate robotic movements and verify the fidelity and safety of the programmed operation. As the learner is guided through a typical simulation scenario, they receive cues and feedback regarding best practices, machine tolerances, and potential hazards.

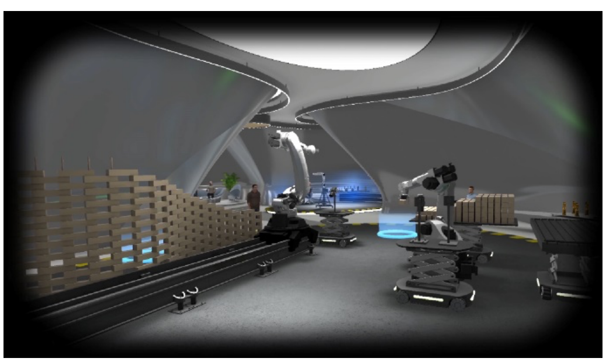

Fig. 2. Scene from the VR learning prototype demonstrating simulation in the Pick and Place lesson.

In this way the learner is coached through the operation using a variety of dynamic feedback mechanisms including audio-visual cues and animations of potential hazards. Using simulated sensor data, the environment associates learner decisions with potential hazards or missteps. If a persistent error or issue is detected, the learner is guided through a refresher scenario that correlates to the error or misstep.

Curriculum Delivery for Virtual Learning Environment

We developed a virtual learning environment prototype to test our pedagogical approach, our curriculum content, and our VR delivery method. To design the VR environment we developed a programming workflow, identified the key user experience interactions, and transposed traditional curriculum to VR curriculum.

Programming Workflow: When selecting our programming workflow to execute the project, we chose a game engine, built 3D assets, designed a real-time control system for simulating robotic movement, and created several animations for tutorials. An important aspect of determining the most suitable software was compatibility in cross-platform workflows. We used the popular game engine Unity to create the learning game. Unity supports highly customizable user interactions and virtual reality development. One of the main considerations for using this program was to ensure flexibility in creating custom elements that are derivatives of 3rd party programs. A particular challenge was developing a system to control robotic movement and toolpath planning. We used RoboDK, a robotic simulation software widely used in the industry. We directed user inputs to the RoboDK library to generate a robotic control code that was subsequently sent to Unity to simulate control of robotic movement. In this way we provided the learner with an experience of interacting with simulated robots that closely approximated real-world interactions.

Fig. 3. Top: Scene from the VR learning prototype demonstrating how the command panel corresponds to Bottom: a physical teach pendant in real world.

User Experience: The initial development of the prototype required creating a user experience that promoted learning and maximized transferred learning from the virtual environment to a real-world scenario. Therefore, we developed virtual input tools and UI interfaces that closely approximate actual robotic input devices. An example of this is how we designed the virtual Command Panel with digital buttons that are organized and located in a similar position as the physical buttons on the Kuka Teach Pendant (a device used to interface with a Kuka industrial robot). Equally important is the user input sequence. We designed the required sequence of user inputs on this virtual interface to closely follow the requirements for interacting with the Kuka Teach Pendant, thus offering a virtual experience that allows high skill transferability to real-world scenarios (See Figure 3).

Transposing Curriculum to Virtual Reality: Traditional methods for teaching robotics typically require in-person instruction so that the student can learn by interacting with a robot and an input device such as a Teach Pendant. As a result, many courses are currently taught with an instructor relying on face-to-face interactions with frequent one-on-one engagement with a student. This organic, real-time format is not transferable to a VR environment. In order to provide the best alternative to in-person teaching, we created a comprehensive, modular script that instructs the student on how to navigate the environment, use the control interface, and interact with the lessons. We used Microsoft's Azure text-to-speech service to create human-like voice overs. This allows the student to engage with a voice over and be guided throughout the entire experience. The audio interaction is a critical aspect of the User Experience design as it allows students to focus on their engagement with simulated robots and input tools without being distracted by on-screen text.

The prototype required us to develop unique workflows for merging the pedagogical framework, curricular content, and technical requirements for its successful implementation. Upon completion of the prototype, we initiated a preliminary testing process with a small group of participants using our introductory lessons, Robotic Anatomy and Robotic Operations. This allowed us to evaluate the effectiveness of the environment for transferring learned content to real-world scenarios. We have developed a testing protocol to continue the evaluation of our immersive learning environment and robotics curriculum.

Future Work

Advances in spatial computing integrated with state-of-the-art AR and VR Head-Mounted Displays offer the possibility for obtaining biometric data including tracking learner movement, haptic interactions, eye-gaze, and heart rate. Access to this data has the potential to enable educators and researchers to analyze information correlated to attention, stress, and confidence levels for improving learning outcomes. The ability to collect and process this type of granular data from learners has led to significant improvements to Adaptive Learning Systems (ALS).

ALS are designed to dynamically adjust the level or types of instruction based on individual ability or preference in order to improve performance (Oxman et al. 2014). In the context of game design, ALS collects and processes information from players to alter the level of difficulty to match their skill level. This process consists of several stages of evaluation: monitoring the player, characterizing the player, generating the assessment, and providing adaptive intervention (Obikwelu and Read, 2013).

Our computer science collaborators have already begun to utilize ALS technology for intelligent real-time monitoring of student performance for limited parts of the Robotics Academy project. They plan to deploy this more fully by integrating two types of data sets. One set of data will be based on the initial information provided by the learner regarding their prior experience, skill level, and learning objectives. The second data set will include a broader array of performance and biometric data which is continuously generated and updated by the learning system. Through the application of deep neural networks to this data, ALS will generate a user profile to fully characterize the learner. With progression of the learner through each scenario, the system will dynamically analyze a growing body of data to customize learning content for individual learners and intervene with appropriate feedback. We anticipate that this customized learning content will enhance the effectiveness of the training curriculum leading to more efficient learning content delivery and improved learner outcomes.

Conclusion

This paper has described the design and development of a learning platform for robotic operations which draws on some of the most advanced technologies. These technologies have the promise to transform education by immersing students in an individualized learning context tailored to their own unique background, learning abilities, and objectives. However, implementation of these technologies remains a difficult and multifaceted endeavor with many interdependent challenges.

The main challenge in deploying these technologies has been the need to reconceive our approach and pedagogy to curriculum design within the conceptual framework of these technologies, rather than relying on our own experience as educators. Teaching robotics is a difficult challenge in and of itself. AI requires a different way of thinking about the roots of communication itself, requiring a robotics curriculum designer to organize information and learning content in radically different ways.

Another challenge has been communicating across disciplines on a large and complex project. The Robotics Academy involved expertise in robotics, architecture, computer science, curriculum development, and engineering. Each of these disciplines have a specialized language for communicating the fundamental concepts of their field as well as a particular framework for viewing how to approach problems. Negotiating the disparities in how different disciplines approached the topic has been a rewarding learning experience while at times, quite difficult to navigate.

The Robotics Academy project demonstrates a new way of delivering a highly complex curriculum for robotics in an engaging game environment that provides the potential for individualized learning. By building the capability for collecting performance data during student interaction in the learning game environment, we have established a new area of research in curriculum design.

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