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Board 24: Development of Multi-User-enabled, Interactive, and Responsive Virtual/Augmented Reality-based Laboratory Training System

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WiP: Development of Multi-user enabled, Interactive and Responsive, Virtual/Augmented Reality based Laboratory Training System

Abstract: The Unit Operations Laboratory (UOL) is a place where third-year chemical engineering students can apply their engineering and science concepts on pilot-scale equipment. However, the physical lab is resource-intensive, requiring protective equipment and constant supervision. In addition, due to limited units for large groups of students, students perform experiments according to the rolling program schedule, making alignment with lecture teaching and hands-on learning challenges. The research team focuses on increasing the accessibility of the UOL by using simulation gaming in standard, virtual reality and augmented reality modalities as an educational tool. The "Virtual Unit Ops Lab" application places students in an immersive simulated environment of the physical lab, where they can get practical experiences without the difficulties of an in-person lab by using specialized headsets and controllers, which allows the student to move and interact with various parts of the machine physically. Developed with Unity software, the application serves as a digital twin to an existing lab, which allows for an immersive simulation of the full-scale lab equipment, in addition to enhanced learning features such as the ability to display the current action performed by the user and to provide visual/audio feedback for correct and incorrect actions. The application also supports the use by multiple "players" (i.e., it has the "multiplayer" option), where multiple students can communicate and discuss their current step. As a work in progress, a non-player-character chatbot (generative AI responses) is being developed for existing applications using OpenAI's GPT-3.5, which provides designated information to a student in a conversational manner. Additionally, a supplemental "Augmented Unit Ops Lab" application uses Augmented Reality, which superimposes three-dimensional flow diagrams onto the Heat Exchanger through the view of a phone camera during the in-person labs.

Introduction

Labs are an essential part of STEM education, allowing students to test theoretical assumptions and execute the practical applications of technology *(1)*. Engineering education is progressive. Freshmen start learning basic tools and programming and gaining basic mathematical knowledge. In their senior year, they begin integrating the learned concepts to solve or create solutions for real-world problems. Aside from knowledge-based learning, laboratory projects provide students with hands-on experience in a semi-controlled learning environment thus practicing critical thinking, knowledge integration, and application skills.

Laboratory teaching is resource intensive, especially in chemical engineering Unit Ops Lab (UOL) courses where projects, equipment and expectations often resemble industrial operational environments. The Unit Operations Laboratory is a place where students gain hands-on experience while applying fundamental chemical engineering concepts and principles to solve and investigate problems associated with pipe, pump and valve systems, chemical reactor systems, heat and refrigeration management, water treatment, solid-liquid/vapour-liquid separation, and process equilibrium. Due to large size and complexity in design, there are usually only 1-2 pieces of the same equipment in the UOL. In this way, the space is maximized to host various process equipment and keep a safe operation distance between them. The operation and curriculum design for the Unit Ops Laboratory can often be a challenge. Chemical process equipment is accompanied by complex operational procedures. Students need to be continuously supervised by TAs and/or technicians. Unit operations classes are often large, and students do multiple labs/experiments at the same time, which makes the logistics of running the labs particularly challenging, especially from the standpoint of safety.

This study aims to address the limitations of UOL teaching practices by using the most recent advances in Augmented Reality (AR)/Virtual Reality (VR) technology to develop a more personalized, easily accessible and available learning/training platform. VR in the words of Biocca & Delaney, is the “the sum of the sum of the hardware and software systems that seek to perfect an all-inclusive, sensory illusion of being present in another environment”. VR can therefore, empower students by immersing them in a customizable simulated environment where they can learn physical process components at their own pace and do so from different perspectives (2, 3). VR technologies are easily scalable, which makes them useful in simulating large process units, such as a distillation tower or a turbine generator, ones that are otherwise difficult to recreate in real life (3, 4). More importantly, VR-based learning environments are significantly more cost-saving than physical constructions and can carry a wide variety of training modules, which makes them an especially amenable choice for schools with fewer financial resources. Finally, VR-based environments have a much higher tolerance for mistakes for students compared to real engineering processes. Students can thus enjoy the freedom of tuning various parameters to any extent and visualize the direct consequence of their process design without suffering but seeing and understanding the consequences of potentially unsafe actions.

This study aims to develop the next generation of education learning systems that will integrate visual, sound, sensory, and sensory-based learning. Cognitive load theory and Bloom's taxonomy were considered in the design of each step/program. The outcomes of the developed technology will enable students to learn in a simulated Unit Operations lab (i.e., digital twin) and experience virtual scenarios that would otherwise be fatal if they occurred in real life. As an added benefit, such a system can provide interactive feedback from AI unsupervised learning, such as Chatbot. Ultimately, students can safely tour an equivalent chemical plant by working in an immersive virtual reality space. They can also observe the manner in which certain fetal scenarios, such as explosions, could happen in real life without being exposed to the actual danger of ones occurring. Virtual operation of the equipment will allow various concepts/principles to be visualized. For example, fluid flow can be coloured to distinguish between high and low temperatures and marked to indicate flow direction or pressure; sounds can be added, and internal configurations of the equipment can be visualized. Combining physical and virtual learning can integrate sensory learning experiences and repetitive practices when needed. The overarching goal is to create an affordable Unit Ops Lab that educators can use to generate immersive, interactive, and responsive digital twins to existing labs and assist students in learning and improving their hands-on skills.

Multi-user enabled, Interactive Training System

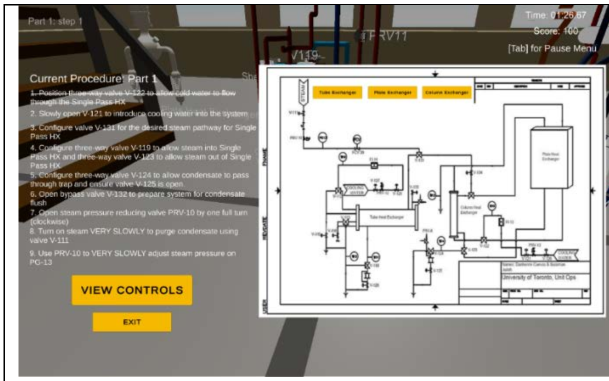
The proposed learning system comprises various programs can be seen in Figures 1 and 2. The overall learning outcome of such a system is to complement the hands-on operational skills to familiarize students with the operation procedures and safety and chemical engineering concepts associated with the equipment/project scopes. The learning system is based on Bloom's Taxonomy, which begins with:

(1) Repetitive practice to remember/familiarize oneself with the operation equipment.
(2) the next learning step continues in the immersive lab environment to visually construct 3D memory and experience through their phone/computer/VR headset. The system is interactive and provides feedback in real-time. For example, in Figure 2b, the 3D interactive games can be played using a normal computer or mobile devices (i.e. iPad) and the correct/incorrect steps are noted. The incorrect steps must be corrected before further operation can be carried out. In the game environment, students can also see the control system and operate it (Figure 1c-d). The control system and output stream information are generated to mimic real-life operations. Students can use the data to solve some problems encountered in the game. They can practice and repeat the experience at their own pace and time. These two steps help students remember a valve's location and how to complete the operating procedures. The immersive 3D works similarly but requires a VR-enabled headset (Figure 2a-b).

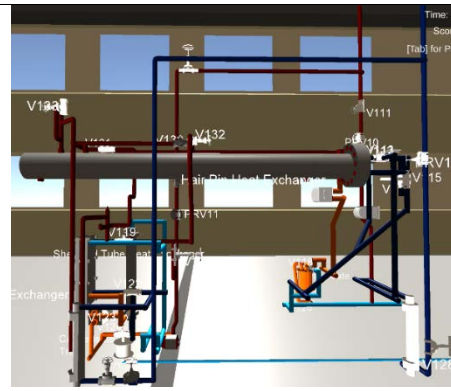
(3) Additionally, students can also use VR walkthrough (Figure 3)to gain an understanding of the actual learning environment prior to operating a real system in the physical lab. Because the VR lab/equipment replicates the real equipment in the lab, this digital twin

technology enables students to have frequent practice and do so without being exposed to physical risks. Students can obtain equipment handling experience and face-to-face teamwork in the physical Unit Ops Lab. Since the VR is multi-user enabled, students can collaborate after the in-lab experience in the virtual environment. During the lab learning, students can be further supported by AR learning system using their mobile devices; images/videos are superimposed with the equipment (ie. Figure 4).

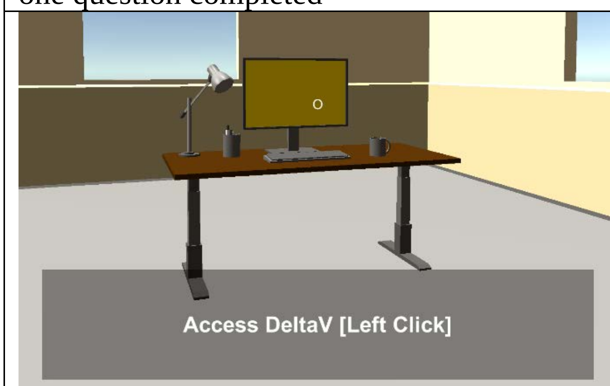
(4) Embedded quizzes in AR/VR can facilitate self-directed testing or initiate the analysis of specific scenarios (ie. Higher learning level on Bloom Taxonomy).



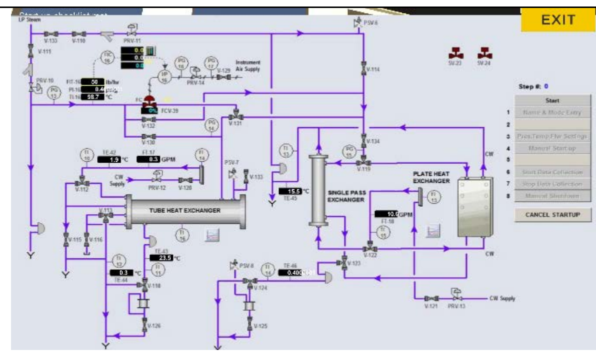
A) Hairpin Heat Exchanger Procedure with one question completed



B) Heat Exchanger Unit on computer screen

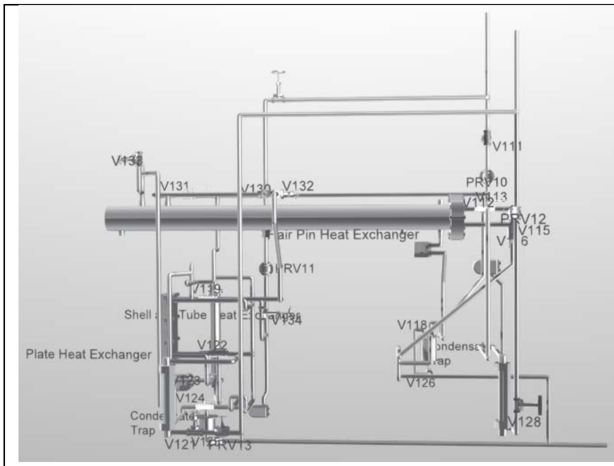


C) Computer station inside VR environment

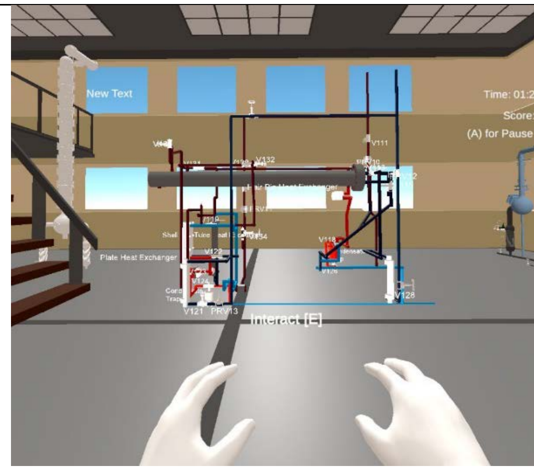


D) DeltaV Control System in the VR environment

Figure 1. Heat Exchanger Unit and DeltaV system inside interactive digital twin, multi-users enabled.

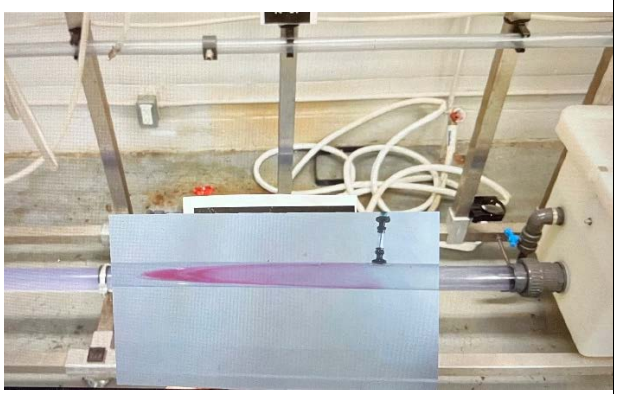


A) 3D P&ID Heat Exchanger



B) 3D Heat Exchanger with controller (user's hand)

Figure 2. 3D Heat Exchanger Unit developed using A) AutoCAD and B) Unity



A) Fluid flow view in AR app created

B)Valve turning instruction in AR app created

Figure 3. AR-assisted app developed for complimenting in-person lab learning.

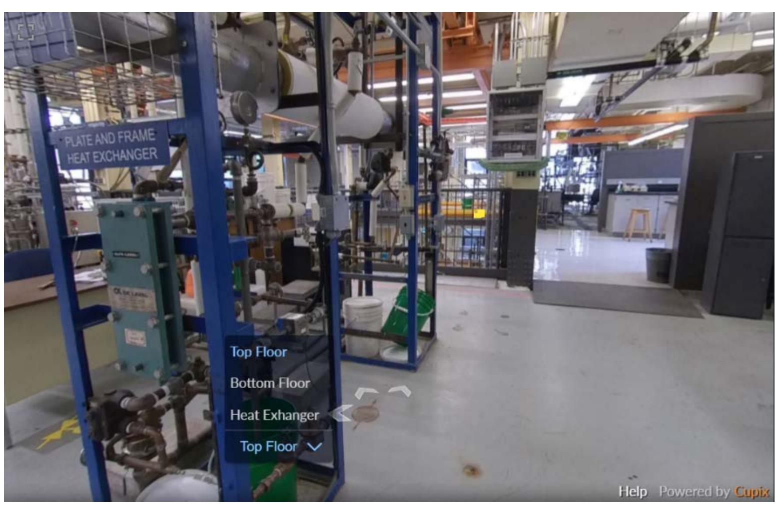


Figure 4. Top Floor in VR walkthrough (Virtual Tour)

Conclusion and Future Work

This paper showcased the work in progress of the new generation of learning systems, combining virtual reality and in-person with AR-assisted technology, expanding the experiential learning spectrum while facilitating a more personalized learning tool. The current work has been expanded to incorporate ChatBot, a generative AI which can interact and respond to questions and provide timely feedback to students. In particular, the learning system was created with the consideration of Bloom's Taxonomy to enable repetitive practices for hands-on skill mastering. Ultimately, this repetitive practice can improve memory and recall competency of the concepts and operations. The second stage of this study will focus on assessment, quantifying the effectiveness of the learning system developed. The ultimate goal is to develop an affordable training and personalized learning system for hands-on mastering while complementing engineering concept integrations, developing critical thinking, and providing safety training in a virtual environment.

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