Development of an Educational Mixed Reality Game on Water Desalination Plants

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***Abstract*— This Work-in-Progress paper reports on the development of a Mixed Reality (MR) game prototype via HoloLens and Unity Engine. We aim to investigate how we can incorporate immersive multimedia technologies such as HoloLens as a potential form of STEM learning for students. This paper also proposes methods for testing the game's effectiveness as a learning tool. In our research, we have developed a prototype of a Desalination Plant in the Mixed Reality model application using the Game Development software called Unity engine. The MR app includes interactions and animations added to the 3D Industrial model, and we cross-built the Unity application to the HoloLens device, allowing the user to interact with the model in a real-world environment. The game aims to stimulate competition by introducing time constraints, game levels and a point system to incentivize students by developing their analytical skills. The game will be followed by a survey tool to assess the educational impact of the game and whether it was beneficial for the students in aiding them in the learning process. The research team has drawn upon the experiences of the Petroleum Engineering department at Texas A&M University at Qatar, who implemented a virtual reality application visualizing LNG spill and Dispersion in one of their research projects [1]. However, in our project, we aim to not only simulate the facility for visualization purposes but also to provide more interactive content for the users in STEM courses and increase students' comprehension of specific topics. In the process of designing the MR game, we aim to address the following research questions: 1) Do students' motivation to learn about plant design and process safety procedures improve after implementing MR? & 2) To what extent can a MR game application teach students to synthesize and design processes typically encountered in the desalination plant to meet needs within realistic constraints such as economics, safety, health & the environment?**

Keywords—Mixed Reality, HoloLens, Desalination Plant, Motivation, Game

I. INTRODUCTION

With the integration of cutting-edge technology into education, new forms of learning are possible in STEM classrooms, encouraging engineers to innovate and develop new technologies while training for tasks that can benefit them in their future careers. In many STEM classrooms, the notion of education has often involved the teacher explaining and analysing concepts while the students listen and try to apply what was taught in their exams. With new technologies, educators can reach more students through a more interactive experience. They can increase the level of understanding for each student by, for example, engaging them with a game-like device that hooks them onto the material and teaches many concepts and theories [2]. A technology that is at the forefront of various emerging technologies is Mixed Reality (MR), which has shown the potential to benefit the academic field in many ways [3].

MR is a combination of Virtual and Augmented Reality that enables users to interact with digital objects (Virtual) in a physical environment (Augmented). In the industry, MR allows employees and students to gain access to valuable knowledge of how real-world facilities and plants work [4]. Implementing MR eliminates the need to be physically present at a factory. It allows high-risk tasks to be replicated with ease and possibly no injuries, therefore proving the effectiveness of MR applications in the industry. For instance, Sims [5] introduced Boeing VR/AR technology for aircraft design and manufacturing, where engineers in helmet-mounted displays can explore the aircraft long before any production begins.

Visual learning constitutes an essential aspect of how students engage with the learning process, and we aim to show that an interactive educational tool like MR can fulfil that role. This multimedia technology would not only help students understand the concepts discussed in class but also stimulates their engagement and their persistence. One study in Malaysia points out the importance of MR when integrated into the learning process by experimenting with primary school students [6]. Their study was showed that motivation levels were high because children never gave up the game. Even when feedback showed the children were playing incorrectly, nobody quit the game until reaching the solution. The children's overall reaction to the system was very positive in the experiment, and most importantly, they concluded that the system didn't make the learning process go wrong. This study suggests that MR can help students with their imagination and originality, which is an essential aspect of our research.

Moreover, this also made us realize the importance of feedback and hints when users are playing the game as it helps them understand and get motivated to finish. In Texas A&M University at Qatar, a student organization called the Aggies Mixed Reality Academy (AMIRA) spearheads Mixed Reality applications in engineering education. Previously, students in the academy designed an MR application for a geography class to visualize the Qatar Map and learn about the various historical architectures portrayed as a 3D figure [7].

Gaining inspiration from the various projects mentioned, our objective in this Work-In-Progress research will be to

identify the effectiveness of Mixed Reality (MR) tools for students in STEM courses, especially in the Chemical Engineering sector. One industrial aspect we chose to replicate was the water desalination plant. We chose this concept since Qatar has freshwater shortages, and thus, desalination plants play a significant role in filtering saltwater so that the residents of Qatar have access to clean drinking water [8]. We wanted to provide students a general idea of how this chemical plant works while developing an appreciation of how chemical plants provide clean drinking water to sustain life. It is also an excellent opportunity for us to fill the niche in the Middle Eastern market on the usage of the MR tools in the educational sector. An important goal we wanted out of this project was to measure if students were motivated or interested in the concepts they learned through our MR application and what tools we can use to measure this impact. Our game will not replace traditional lectures but rather act as a supplementary tool to the lecture and can be equivalent to homework or extra credit. Section II will describe the main theories that we utilized to formulate our application for chemical engineering education. Section III will elaborate on the implementation of our ideas to make a working prototype of the MR application. Finally, Section IV will discuss the survey tools that we aim to test on users.

II. CONCEPTS

This section will describe the main theories that we utilized to formulate our application for chemical engineering education and the research questions we implemented for the project.

A. Synthesis and Design of Chemical Plants

To gauge the effectiveness of using this high-tech tool as a mode of teaching, we wanted to understand how students are learning to synthesize and design processes to improve their proficiency within realistic constraints such as economics, safety, health and the environment. One of the key challenges for chemical engineering students is learning how to solve plant facility problems through synthesizing technical factors that can be taught through lecture with contextual factors that often depend upon experience.

Previous studies have explored innovative methods of teaching plant design in chemical engineering courses, such as [9], who found that a virtual field trip was a helpful supplement to real field trips to chemical plants, and [10], who designed a problem-based learning method for teaching plant design. We are aiming for a similar self-directed learning process [11] where students are given the freedom to learn, test their understanding and synthesize many technical details to make decisions about plant design, specifically a water desalination plant.

B. Gamification

To understand student engagement and attitudes towards learning, we examined previous studies on active learning and gamification. We aim to encourage active learning where students participate and place effort into learning rather than passively listen as done during lectures [12]. One form of active learning is gamification, which means adding game-like elements into activities not usually considered as a game [13]. Gamification can boost a student's motivation and engagement with a subject. When we think of video games, there is a concept of a scoreboard where users can compete against each other. It also fosters friendships and promotes a collaborative environment amongst the users. Free online services such as Khan Academy allows users to watch videos and solve exercises, earning energy points, and badges based on their progress that can act as a great motivator [14]. Coller [15] introduced making a computer video game called NIU-Torcs for a numerical methods course where Mechanical Engineering students received homework to write a program to race a simulated car around the track. The data from conducting the homework via the video game showed that students experienced a greater sense of motivation, engagement & also felt creative compared to the homework completion in other engineering courses. Coller [15] also mentioned that the video game approach raised the level of challenge and that students had a clear idea of the goals and were provided free-flowing feedback on their performance. We aim to bring a similar experience to engineering education by turning the lecture sessions into a fun & engaging activity, but with the use of HoloLens. Students can see a visualization of the concepts they learn on HoloLens and play mini games that will transform learning into application in real-world scenario. The survey tools will assess the impact of gamification in a chemical engineering plant design course and will be discussed in Section IV.

C. Research Questions

We came up with the following research questions to better understand the impact of MR on student learning: *1) Do students' motivation to learn about plant design and its process safety procedures improve after implementing MR? & 2) To what extent can a MR game application teach students to synthesize and design processes typically encountered in the desalination plant to meet needs within realistic constraints such as economics, safety, health & the environment?*

To answer the above questions, we are in the process of developing survey tools that will measure the student's engagement with the subject and one of the course learning outcomes after implementing Mixed Reality technology. The survey tools will be explained in detail in Section IV. Based on the theories and motivations discussed, we started the process of designing different games that focus on the core topics that would benefit students taking a course in chemical engineering plant design. This course focuses on desalination plants that play a significant role in Qatar's economy.

III. METHODOLOGY

Our project relies on the assumption that students in upper level Chemical Engineering courses are familiar with the concepts, and therefore the game will act as a supplementary tool to the lecture. To begin, we decided to make a series of 2 mini-games where the first one was a puzzle, and the second game was multiple-choice and fill in the blank questions. Most of these mini-games were made into levels of increasing difficulty to provide a challenge for the students. We made a rough sketch on paper and then started designing on a gaming software called Unity. Unity is a 3D video game engine platform that can be used to create Mixed Reality simulations and game designs. It also provides various tools to add animation effects to the objects. One way to design Mixed Reality applications on Unity is by using the MR Toolkit

library that is free for non-commercial projects and easy to integrate in an OpenGL environment [4]. MR Toolkit library offers the possibility to recognize objects without the usage of high-end tracking systems. Our team is composed of three students, where two of them are in charge of handling the Unity software and writing scripts to add animation effects to the components. The other member is in charge of designing the artistic layout of the game and recreating 3D parts using SolidWorks. This section will introduce how to use the HoloLens, the features of our game design and how we customized it to explore our research questions.

A. Game-Play Instructions for HoloLens

To play this game, the user needs smart glasses called HoloLens that allows the user to see a virtual image embedded onto the physical surrounding. The user can interact and manipulate the virtual objects and move them from place to place to achieve mission goals that allow them to transfer to the upcoming level. We can harness this technology to bring a user's technical and abstract concepts to life by having a visual depiction of the ideas they learn. The main methods to interact in a Mixed Reality environment via HoloLens are using gaze, gesture, and voice. Gaze involves targeting the hologram, gesture allows the user to select or interact with the hologram, and voice adds another dimension to interactivity where users can say commands to virtual objects. Voice can also be used to seek assistance when a user is stuck on stage in the game. Figure 1 shows the possible hand gestures. Users can perform the bloom gesture in opening the application while the remaining gestures help the user interact with the objects.

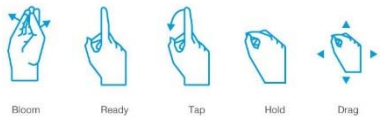

Figure 1. HoloLens Gestures

B. Mini-Game

The objective of each mini-game is to act as a supplementary learning tool to stimulate a user's understanding of the concepts in a fun and engaging manner. The student will learn about the concepts as they play the game where they can move around, grab objects, and see descriptions of the various components as they explore the game. The overarching theme of the mini-games is a water desalination plant, and each mini-game will cover a different aspect. Mini-Game 1 is the Desalination Plant puzzle that encourages the student to put together various components in the right order to replicate a functional desalination Plant. Mini-Game 2 tests the user's technical proficiency in the desalination plant processes. We have designed these games as level-based, composed of three levels. Each level will test a user of a more challenging concept, and all these levels are linked together. Linking the levels helps the user understand how individual parts fit together as a whole towards the end. While we want users to develop a big picture of whatever they learn, we mainly want them to enjoy the process of learning and actively participate in developing their proficiency in a subject matter.

An example of mini-game 1 is shown in Figures 2a-d. The figures show a walkthrough of how an individual component can be dragged using the description provided. First, the user must place the component called 'Flocculation' in the facility section. In figure 2a (top left), the user first gazes at the element, which provides the component name in yellow font and its description in blue font. This interactive text that is

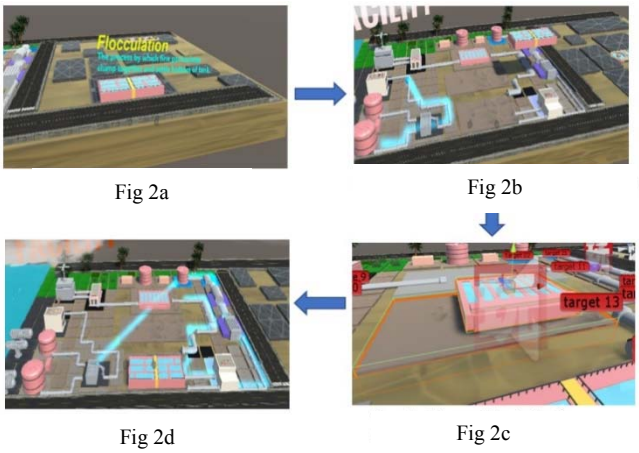

Fig 2a Fig 2b

Fig 2d Fig 2c

Figure 2a-d. Process of gameplay in Mini-Game 1

centralized on top of the model allows the user to see the text and the 3D model at the same time. In textbooks, the text and the figures can be in different locations of the page, and pictures are 2D that cannot be rotated or moved, thus reducing the visual form of learning. Our application provides a full 3D representation of the figure with the relevant description. The description for 'Flocculation' tells us that 'fine impurities must clump together and fall at the bottom,' meaning that Flocculation gets the impure water ready to be filtered easily by the filtration components. If the user doesn't grasp the concept, we provide a short video clip about the component. Once the user decides where the component should be placed in the water desalination process, they can use a hand gesture to drag the component to the desired location as shown in figure 2b (top right). Figure 2c (bottom right) shows trigger collider acting as the logic controller for the game as it detects whether the object is placed in the correct position. If it detects the right object, then the object stays in position as shown in figure 2d (bottom left), and if it doesn't, it reverts to the inventory. When the user has tried multiple times to place the component in the facility section incorrectly, our game will hint the user to draw attention to the area where he can put the object. These hints would keep getting easier as the user keeps making the same error more than once, as shown in figure 3.

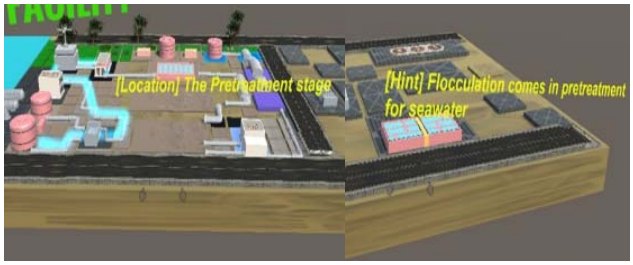

Fig 3. Hints are given to the user

Mini-game 2, as shown in figure 4 below, aims to test the user's understanding of the desalination plant by asking questions that require the player to drag letters into their designated place to answer questions, similar to filling in the blanks. Thus, the concept is to ask questions related to the process safety of the desalination plant, prompting the users to think about what safety factors are necessary to keep the plant in safe running condition. Like mini-game 1, this mini-game will have a time constraint to simulate the user's competitiveness.

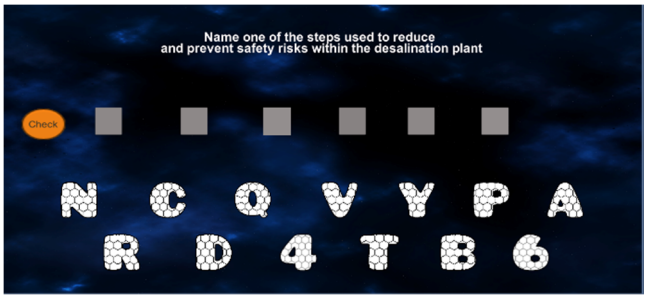

Fig 4. Process of the gameplay in Mini-Game 2

IV. SURVEY TOOLS

We are currently developing the tools necessary to measure the learning experience of chemical engineering students using HoloLens technology. The survey tools will be used pre- and post-intervention to measure the MR technology's effectiveness in enabling students to synthesize concepts better and understand the societal and environmental implications encountered in a real-world plant facility. There will be a control group who will attend the lecture only. The experimental group will attend a lecture and participate in the HoloLens experience. We came up with three different tools for measuring our research question: questionnaire, interview, and quiz. The questionnaire is designed to get qualitative feedback from students pre- and post-experience on their interest in the concepts of the game and the game experience itself. Potential questions include “I feel motivated to learn more about the desalination plants” and “I can understand my concepts better through the HoloLens gameplay format.” The research team will also conduct interviews to analyse the users’ learning experience and how they felt after using the HoloLens. Finally, all users will take a pre- and post-intervention to test their abilities to synthesize and design plant processes. Usually, questions in a quiz tend to test a student’s ability to find the “correct” answer by applying some concepts. However, we want students to make complex decisions, such as considering the ethical, environmental, and safety concerns like those encountered in a real-life desalination plant. The MR game will test not only a student’s ability to design a plant from scratch using technical knowledge, but also get an awareness of the societal factors that impact the running the desalination plant.

V. CONCLUSION

This project mainly aims to complement the learning process of technical concepts through the implementation of multimedia technology like HoloLens. We want students to be engaged in the subject matters they learn, and our project provided a visual element to their learning process. The team has already built a working prototype of the MR game, as shown in the methodology section. The prototype includes a map scene that allows the user to navigate the game, three tutorials that acquaint the user to the basic gesture features of the HoloLens, and two mini-games that teach students on the processes of a desalination plant. We plan to test if this prototype game increases student interest in a water desalination plant and if this game improves the students’ performance on the learning outcome. This project also gave the research team a new learning experience and perspective towards analysing the development of Mixed Reality in Education. Additionally, our project can be a stepping point for individuals to expand their research abilities to implement Mixed Reality technology to create more informational tools for self-educating purposes.

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