Exploration of Technology Aided Education: Virtual Reality Processing Plant for Chemical Engineering Process Design

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Abstract

This work-in-progress study will explore technology aided education in the form of a Virtual Reality (VR) application used to support learning outcomes in a chemical engineering capstone course. VR has the ability to immerse users in a simulated environment and provide them with experiential learning opportunities. Most undergraduate chemical engineering students are required to design a chemical plant for their capstone design project without ever having visited or interacted with a full-scale processing plant and could benefit from the immersive experience that the VR tool would offer. This study will be conducted over a two-year period from September 2019 to May 2021. During the first-year, surveys and design challenges will be conducted without the use of the VR chemical processing plant. The data from the first year will establish a baseline that evaluates how learning outcomes are being met by the course without the VR application. During the second year the surveys will be given again in conjunction with the VR educational tool. The tool will give students the ability to view and interact with the unit operations inside a chemical processing plant without special training, expensive protective equipment and security clearance. Students will complete a number of challenges in VR and will be evaluated on their comprehension and invited to provide feedback on the effectiveness of the VR tool. The effects of VR on student comprehension, retention, and chemical processing design competency will be evaluated based on the data collected. This paper will discuss the initial design of the VR chemical processing plant, data from the non-VR cohort and a description of the research methods to be used during the final portion of the research.

1.0 Introduction

This work-in-progress paper outlines the initial stages of a study examining the effectiveness of using Virtual Reality (VR) in an undergraduate chemical engineering design course. VR is an immersive technology that has the ability to place users in a simulated environment. In this study an educational tool will be developed and implemented in a chemical engineering capstone course at Queens's University to allow students to explore and complete design challenges in a fully immersive VR chemical processing plant.

The chemical engineering students at Queen's University are required to take a capstone course in their final year of the program. The goal of this class is to have the students use the skills they have learned over the course of their degree to complete a large comprehensive design project. This course assesses the design competency that the students have developed and their ability to apply those skills to an engineering project. Although the students will have seen the technical concepts needed to complete the work and have been exposed to design tools in earlier courses, for many, this will be the first time applying their engineering design skills within the context of a full-scale chemical processing plant. As a result, when completing the design project in the past there were some clear gaps in the students' physical understanding of a full-scale processing plant. This often resulted in student designs that were disproportional in size, cost and generally a poor representation of real-world processing plants. In the past, student tours to active processing plants were organized to bridge the gap between school and industry, and to provide some exposure to industrial processing plants; however, due to increased security and safety measures, tours capable of accommodating large numbers of students are becoming increasingly difficult to arrange.

A VR chemical processing plant provides an opportunity for students to tour a full-scale chemical processing plant in a safe and more interactive fashion. VR stations on campus will be used to eliminate travel requirements. The risk associated with using a VR application is very low and the plant would be designed to allow increased student interaction to promote an experiential learning approach.

2.0 Virtual Reality and Education

Simulations have been used in education for many years with success. In a study of technology-based simulations used in STEM education between 2001 and 2010 it was found that for all studies that compared with simulation against without simulation, positive results were reported for with simulation. Simulation effected posttest scores positively up to a 1.5 effect size and had an even greater effect size up to 2 when it came to motivation and attitude [2]. VR is a technology that brings a new level of immersion to simulation and has the ability to create more realism and increased interaction.

Using VR in the classroom has been done before with success, when used in an undergraduate mechanical engineering class Syed et al. found that it helped students better grasp subject matter [3]. In another study when a VR tool was used to teach sorting algorithms in a software engineering class, students who used the VR learning tool performed better on a quiz than those who did not use the tool [4]. There is also research that suggests VR may be able to meet the needs of students with different learning styles. Lee et al. preformed a study with students who reported having different learning styles and concluded they could not detect significant gaps in performance when these students were evaluated using a VR education tool [5].

Over the course of this research VR will be explored in a low-cost scenario, where students will use their mobile devices to take a tour of the chemical processing plant, and in a higher cost scenario where they will use a fully immersive interactive commercial VR headset. Researchers that created two VR experiences for a physics class found that both low cost and high cost VR was beneficial to students and students, and students reported positive learning experiences after both types of immersion [6]. In a survey of pre-service teachers, it was found that an overwhelming majority had a positive perception of VR, even if they had never used it before. This suggests that the technology has the ability to engage and motivate learners, and could bring many benefits if paired with good content [7].

VR for education has grown in popularity since the technology’s inception, and in a systematic review Radianti et al. found that research related VR for higher education was abundant. The researchers conclude that much of this research seems to be in its early stages, and although the results seem encouraging more work will need to be done to fully understand this technologies impact on the classroom [8].

3.0 Research Questions

To assess the impact of the VR education tool on a chemical engineering undergraduate student's design ability, the following research questions will be evaluated:

1) Do students who use the VR tool perform better on design problems compared to students who do not use the VR tool?

2) Are the distribution of grades for the design problems of the participant groups affected by student participation in the VR challenge?

3) Do the students feel that VR helps them learn course concepts?

4) Does the VR tool increase student's confidence levels when completing engineering design challenges on chemical processing plants?

5) Do participants feel the VR experience enhanced their design abilities and gave them an advantage when moving from their undergraduate degree to industry or post graduate work?

4.0 Methods

The research will be completed in two phases, one without the VR tool which will be used as a baseline to understand how engineering design is taught, and a second phase that will evaluate the contribution of the VR tool. Figure 1 illustrates the methods that will be used to collect data from the participants and how these methods connect to each of the five research questions.

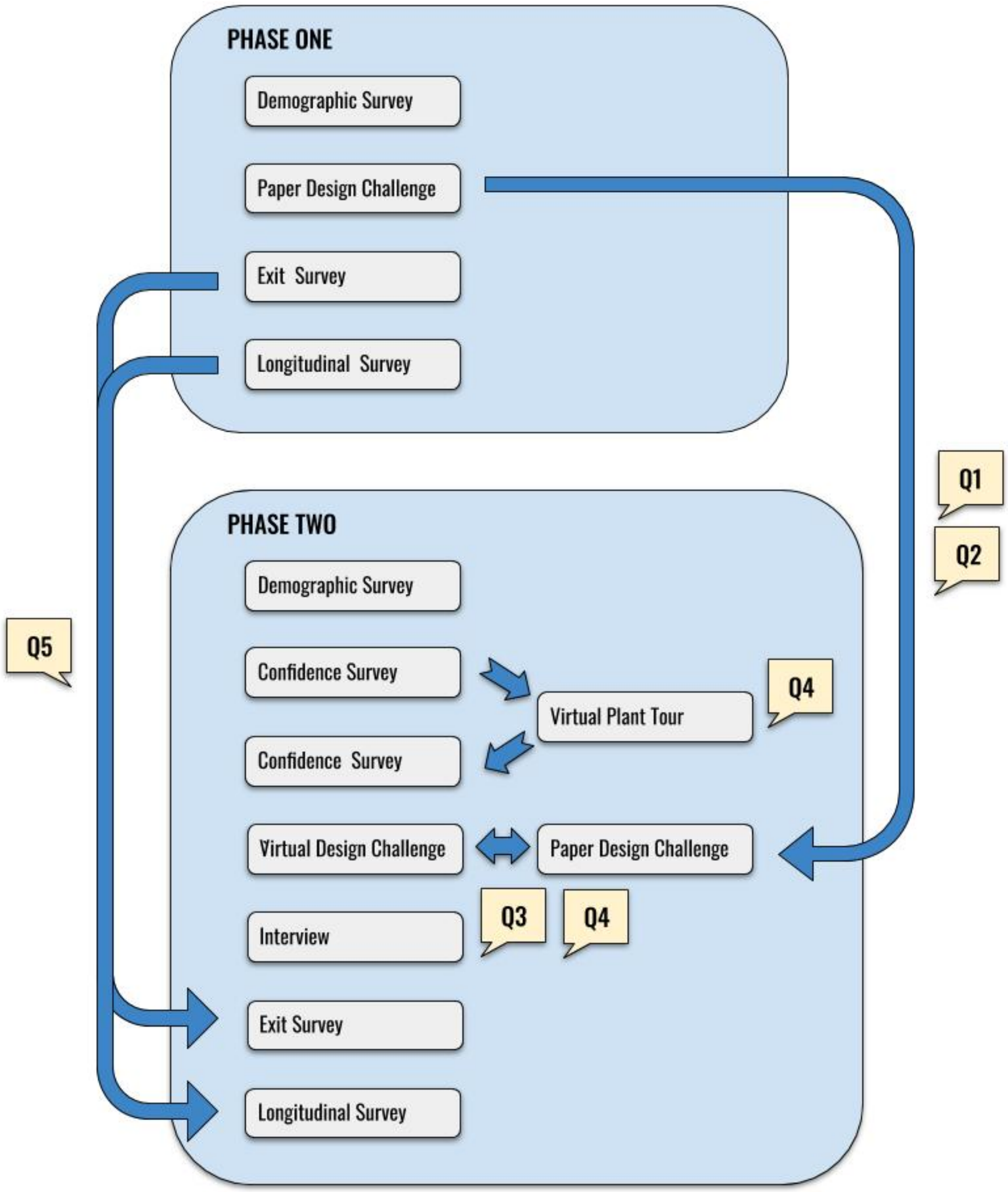

Figure 1: Research Flow Diagram, Q1-Q5 represent each of the five research questions and show how each question will be addressed during the research.

Evaluating the students' design abilities will be a core part of this study. Therefore, it is essential to identify the design framework that will be used in the study and what aspects and elements will be assessed. Dym et al. preformed research on design pedagogy and characterized engineering design as the process of scoping, generation, assessment, selection, and idea realization. This engineering design framework will be used in this study and the key elements in this design process are illustrated in Figure 2 [9]. In 2013 Khalaf et al. used these concepts in a first-year engineer problem-based learning course with success [10]. In this study, when assessing the design problems, an evaluation rubric based on the Engineering Design Framework below will be used. Each dimension in the rubric will correspond with an element in the framework. How well each student performs on the various elements in the design framework will enable the researchers to assess their design abilities.

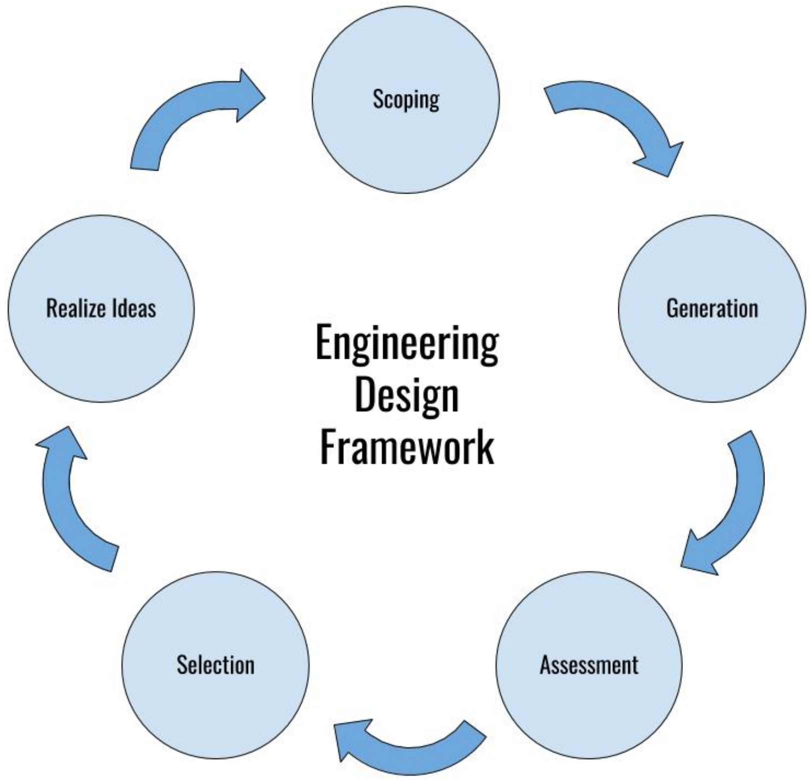

Figure 2: Engineering Design framework used by Dym et al in [9]

4.1 Phase One

In this phase the course will be executed without a VR component. The research will look at approximately 100 participants that are registered in the chemical engineering capstone course at Queen's University from September 2019 to April 2020. This phase will be focused on obtaining baseline data to understand and assess student design skills. A demographic survey will be given to the students so we can explore how age, gender and previous experience may affect the study. During the course, two separate design problems will be given to each individual student and assessed against the design rubric. The first design problem will require the students to develop a standard operating procedure for one of the unit operations in the chemical processing plant. The second design problem will present a plant troubleshooting scenario and examine the students' ability to develop a solution to solve the problem that is causing issues in the processing plant. At the end of the course the study participants will be given an exit survey to evaluate the perception of their design abilities. Six months after the course has ended, participants will be asked to complete a longitudinal survey to reflect on how they believe the course has impacted their chemical engineering process design competency.

4.2 Phase Two

In this phase the course will be executed with a VR component integrated into the course deliverables. The research will look at approximately 100 participants that are registered in the chemical engineering capstone course at Queen's University from September 2020 to April 2021.

4.2.1 Plant Tour

During the first part of phase two the participants will take a tour of the virtual chemical processing plant using google cardboard and a mobile device. A survey will be given before the tour to assess the students self-perceived confidence levels when interacting with a chemical processing plant, and then again after the virtual tour to assess the impact of the VR experience on their self-reported confidence levels.

4.2.2 VR Design Problems

In phase two the capstone course will be delivered using the VR tool integrated into the course deliverables. The two design problems used in phase one will once again be evaluated. The students will first complete the standard operating procedure tutorial problem and corresponding VR challenge. They will be split into two groups and a cross-over study approach will be employed as seen in Figure 3, one group will complete the paper-based problem first, and then go through the VR challenge, while the other group will complete the VR challenge first. This process will take place a second time when the students complete the tutorial problem and VR plant troubleshooting challenge. An assessment will be made for each of the four activities and the grades of the research study participants will be collected.

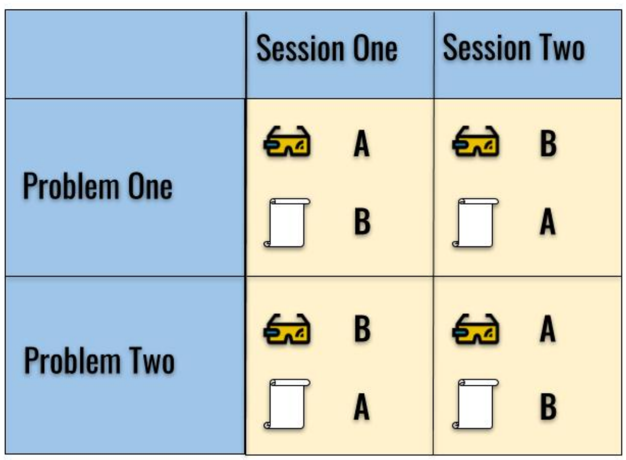

Figure 3: Session plans for the paper tutorial and VR tutorial in phase two for participant groups A and B

Participants will be invited to an interview to give feedback on their experience with the VR tool. The interview will take place in a semi-structured format where they will be asked how realistic they thought the experience was, how much they believe it contributed to their education, as well as given time to discuss other questions and comments regarding the VR tool. At the end of the course the study participants will be given an exit survey to understand their opinion of the course and how they think the VR tool contributed to their learning. Six months after the course has ended participants will be asked to complete a longitudinal survey to reflect on how they believe the course has impacted their professional lives, and if they believe the VR tool specifically helped prepare them for industry or further schooling.

5.0 Design Problems

To evaluate the chemical engineering students' design proficiency, two different kinds of problems will be used, standard operating procedure and plant troubleshooting. These problems were developed to evaluate design competency in chemical engineers by evaluating their ability to participate in design thinking.

5.1 Standard Operating Procedure (SOP)

For the purposes of this paper, a standard operating procedure is a comprehensive set of instructions to complete a task in the chemical processing plant. These documents are used in many places in the plant, for tasks such as refilling empty holding tanks, scheduled safety checks, and more. Writing these procedures is an important skill, as it is up to the engineer to ensure proper handling of chemicals and that safety concerns are met in the day to day operation of a chemical processing plant. This problem requires students to use divergent-convergent questioning, and to make design decisions. The students will have to understand all of the ways the procedure can be completed, then ask themselves questions to converge on a solution. They will then have to make design decisions to create the best possible SOP. This exercise showcases student ability to participate in the scoping, generation, assessment and selection phases of engineering design.

For the paper-based tutorial problem the students will be asked to write an SOP based on filling a Caustic Soda storage tank. The students will be provided with a Caustic Soda Handbook that outlines some of the different ways the chemical is delivered and the storage tank is filled, as well as some safety information and considerations that they may need to consider when thinking about handling this chemical.

For the SOP VR challenge students will create an SOP and watch the filling of the tank take place in the virtual chemical processing plant space. Students will be given the same handbook that was provided for the paper-based question and then have a variety of steps that they can draw from to create the SOP. They will also be able to walk around, interact with and explore the equipment that they will have access to in order to complete the task. Once the SOP is created students will be able to follow their own plan and see how successful they are at completing the task.

5.2 Chemical Processing Plant Troubleshooting

During the lifetime of a chemical processing plant, problems will occur that may cause the plant to run inefficiently or not at all. The students will be given a scenario in which a problem was found with the plant after a routine check and they will have to find the cause of the issue. This problem requires students to think about design systems, as they will have to consider the chemical processing plant as a whole to determine the cause of the problem and find a solution. This problem will showcase student's ability to generate possible problems, assess the plant and select the best course of action based on their findings.

For the paper-based plant troubleshooting problem, students will be given a copy of the chemical processing plant's piping and instrumentation diagram (P&ID) and a problem with the plant that they must develop a solution for. The problem may be a non-emergency alarm or a gauge value that is not ideal. They will be asked to create a flow chart outlining checks that they will make and activities to be carried out following the result of each of their checks.

For the plant troubleshooting VR challenge students will be dropped somewhere in the plant and a notification will appear on screen detailing the problem. Students will have access to a tool kit which will allow them to check different plant systems and eventually fix the problem. They will have access to the plant's P&ID and may check it at any time while in the simulation. Their actions will generate a flow chart that they will be able to review at the end of the simulation and express if they would do things in a different order next time.

6.0 Analysis

This research aims to get a better understanding of the impact of technology aided education on engineering design education, specifically in the chemical engineering capstone course at Queen's University. This mixed methods study will look at different kinds of data to try and compose the fullest picture of how the tool will impact this course, and the feelings towards VR of the participants.

On a quantitative level, students will receive grades from the paper-based tutorial problems in both phases, as well as on the VR challenges in phase two. These grades will be analyzed to understand if students perform better in the VR space than they do on paper. We will also be able to see if the grades of the participants in phase two are affected by the order they complete the paper-based tutorial problem and VR challenge in. Students will also answer surveys from which we will be able to map confidence levels to understand how equipped students feel to work in chemical processing plants, and view how these confidence levels compare across phases. The surveys will have students rate their confidence level and from these ratings a confidence score will be generated and analyzed. Discussion results from the interview will be compared to survey results to understand in more detail exactly how the students feel the VR tool impacted their course experience.

The longitudinal survey will give us an understanding of the implications of the VR aided education in the long term, and if participants feel like it was a valuable portion of their education after being exposed to the professional world.

7.0 Conclusion and Implications

If the results of this study are positive VR education will be incorporated into the chemical engineering capstone course at Queen's University long term. Additional steps could also be taken to incorporate VR aided education through the design spine of the chemical engineering program. More research should be done to understand the total impact on the program, and what the effect would be if students were exposed to the VR tool earlier and more frequently in their undergraduate degree. Further testing in other disciplines of engineering at Queen's University would help to fully understand the impact of VR on design education. It would also be interesting to share this educational tool with other accredited post-secondary institutions to see if the results can be replicated in their engineering programs. For future work, eye-tracking data could be collected from this tool to develop intelligent aids to continue to improve outcomes in engineering design.

8.0 References

[1] W. Alhalabi, "Virtual reality systems enhance students' achievements in engineering education," *Behaviour & Information Technology*, vol. 35, no. 11, pp. 919–925, 2016.

[2] N. Rutten, W. R. van Joolingen, and J. T. van der Veen, "The learning effects of computer simulations in science education," Computers & Education, vol. 58, no. 1, pp. 136–153, Jan. 2012, doi: 10.1016/j.compedu.2011.07.017.

[3] Z. A. Syed *et al.*, "Evaluation of Virtual Reality Based Learning Materials as a Supplement to the Undergraduate Mechanical Engineering Laboratory Experience," p. 11.

[4] A. Akbulut, C. Catal, and B. Yıldız, "On the effectiveness of virtual reality in the education of software engineering," *Computer Applications in Engineering Education*, vol. 26, no. 4, pp. 918–927, 2018, doi: 10.1002/cae.21935

[5] E. A.-L. Lee, K. W. Wong, and C. C. Fung, "Learning with Virtual Reality: Its Effects on Students with Different Learning Styles," in *Transactions on Edutainment IV*, vol. 6250, Z. Pan, A. D. Cheok, W. Müller, X. Zhang, and K. Wong, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 79–90.

[6] Z. A. Syed *et al.*, "Evaluation of Virtual Reality Based Learning Materials as a Supplement to the Undergraduate Mechanical Engineering Laboratory Experience," p. 11.

[7] G. Cooper, H. Park, Z. Nasr, L. P. Thong, and R. Johnson, "Using virtual reality in the classroom: preservice teachers' perceptions of its use as a teaching and learning tool," *Educational Media International*, vol. 56, no. 1, pp. 1–13, Jan. 2019, doi: 10.1080/09523987.2019.1583461.

[8] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," *Computers & Education*, vol. 147, p. 103778, Apr. 2020, doi: 10.1016/j.compedu.2019.103778.

[9] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering Design Thinking, Teaching, and Learning," *Journal of Engineering Education*, vol. 94, no. 1, pp. 103–120, 2005, doi: 10.1002/j.2168-9830.2005.tb00832.x.

[10] K. Khalaf, S. Balawi, G. W. Hitt, and A. Radaideh, "Engineering Design EDUCATION: When, What, And HOW," *Advances in Engineering Education*, vol. 3, no. 3, pp. 1–31, 2013.