Lessons Learned from Implementing Virtual Reality in an Introductory Engineering Course

Dr. Fadi Castronovo, California State University, East Bay

Hi! My name is Fadi Castronovo, I am an Assistant Professor of Engineering at Cal State East Bay. I received my doctorate in Architectural Engineering at Penn State with a minor in Educational Psychology. I am strongly focused on my teaching and research. In my teaching, I strive to provide an engaging and active learning experience to my students, by applying innovative technology and researched pedagogical interventions. I translate this passion for pedagogy in my research by evaluating the intersection of innovative technology and learning.

Dr. Robert Schaffer, Mission College

Dr. Bob Schaffer is a professor and department chair of the Engineering Department at Mission College (Santa Clara, CA). He is also a lecturer at Santa Clara University where he teaches a variety of classes in the General and Electrical Engineering departments. His classes include Introduction to Engineering, Introduction to Computing for Engineers, STEM Outreach in the Community, and Digital Signal Processing.

Ms. Varsha Reddy Kandi

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ABSTRACT

In this paper, the research team will discuss the lessons learned from the design of a new Introduction to Engineering course at two California institutions: a community college, and a university. The design of the course focused on engaging students with innovative technology and empowering students to develop technology-based engineering solutions for their semester project. The goal of this paper is for the authors to share their experiences in 1) designing VR-infused activities and design challenges for their courses, 2) developing two VR-ready classrooms, and 3) implementing virtual reality (VR) in their classroom environments. The design of the class was focused on the adoption of group-based problem-solving, educational games, and VR activities to enhance the learning of the students. The course not only focused on implementing such technology for the students to use as a learning tool but also engaged the students in developing new technology-based activities as part of their semester project.These courses leaned heavily on tools available in the Visualization and Immersion Classroom and the Experiential Reality Laboratory at the university and community college that were developed to support this course work. The authors present the learned lessons to support other instructors that are planning on implementing innovative technology in their courses.

1. Introduction

In higher education, the growing adoption of innovative pedagogy, such as active and experiential learning and online instruction, requires instructors to use a wide variety of educational techniques. Such methods include the use of both non-technology and technology-based activities, including group problem-solving, educational games, and virtual reality (VR). Research on educational games has increased steadily over the past two decades, and numerous studies have illustrated their benefits with respect to student learning [1]–[4]. For example, Squire and Barab found that simulation games helped students increase their knowledge of history, politics, and geography [5]. Castronovo et al. found that educational games can support students to develop the metacognitive skills necessary to manage civil engineering projects [6].

One particular technology that has been under increased research scrutiny is VR. VR provides learners with a sense of spatial presence and immersion that is incomparable to other media [7], [8]. For example, Thorsteinsson and Shavinina found that immersing students in VR experiences aligned with the class's textbook increased their conceptual and experiential knowledge [9]. The benefits of including VR in a classroom go beyond the cognitive dimension to benefit the emotional as well. The implementation of VR in the classroom environment is still in its early stages and often analyzed through case-by-case research. Further research needs to be performed to evaluate its benefits in an engineering curriculum.

With this research opportunity, the authors of this paper decided to spearhead the implementation of VR in the engineering curriculum at their institutions, Cal State East Bay and Mission College. Therefore, the goal of this paper is for the authors to share their experiences in 1) designing VR-infused activities and design challenges for their courses, 2) developing two VR-ready classrooms, and 3) implementing VR in their classroom environments. First, they will share their process in redesigning their *Introduction to Engineering* courses. In this revamped

course, the authors designed several activities that include VR simulations and educational games that are aligned to the courses' educational objectives. Additionally, they will share the development of three course projects that engage the students in developing new technology-based activities and connection to their curriculum and campus environment as part of their semester project. Second, they will share their experience in retrofitting, with VR technology, two computer laboratories, the Visualization and Immersion Classroom, and the Experiential Reality Laboratory, at their respective institutions. Third, and lastly, they will share their experiences with the implementation of some of the designed activities.

2. Literature Review

2.1 Virtual Reality in Education

The growing implementation of multimedia in education is a direct response to the benefits that such media brings to the learning process. In particular, visualization and visual representations have illustrated as powerful media to support and aid cognitive operations, such as problem-solving and knowledge acquisition [4], [10], [11]. What visualizations provide, in comparison with traditional media, is an experiential learning environment [12]. A type of visualization method that has been a growing focus in research is VR, as it provides learners with a sense of spatial presence and immersion that is incomparable to other media [7], [8]. For example, Thorsteinsson et al. found that immersing students in VR experiences, that are aligned to the class' textbook, increased their conceptual and experiential knowledge [9]. In their experiment, Thorsteinsson et al. allowed students to engage in trial and error activities to solve problems by testing their hypothesis in a simulated environment that provided feedback [9]. In another example, Kandi et al. found that by engaging students in a VR construction site, they were able to gain stronger design evaluation and mistake identification skills [13]. Specifically, students that were engaged in a VR environment would find a higher number of design mistakes than when asked to evaluate the same construction site on 2D paper drawings. The benefits of including VR in a classroom go beyond the cognitive dimension but have an effect on the emotional as well. For example, according to Riva et al., VR has the capacity for users to connect emotionally with the simulated environment, causing a strong mental connection with the content [14].

While VR has been evaluated through a case-by-case research methodology, further research needs to be conducted to analyze its impact on an engineering curriculum-wide implementation. Based on previous research, such curriculum-wide implementation has been performed in the field of medicine, but not in engineering education [15]. In their implementation, Bintsadt et al. aligned their curricular learning objectives to the learning objectives of the VR simulation and found that the students had a strong positive response [15]. Based on this research gap in the engineering education curriculum, the benefits of VR need to be further investigated.

2.2 Educational Games in Engineering Education

Similar to VR, simulations and educational games have shown immense potential in stimulating engagement and motivating students in learning. Educational games provide students with environments that allow them to fail fast, problem-solve, and receive immediate feedback by allowing them a safe environment to explore and test their skills [1], [16], [17]. Such environments give users the chance to engage in learning by doing and have meaningful experiences [5]. These games allow students to be engaged through multiple types of representations and have the chance to integrate verbal, aural, and visual information all at once, while not overloading their cognitive capacity [18]. Additionally, educational games are engaging, fun, and promote users' curiosity [19]. Educational games have been steadily subject to research in the past two decades, and numerous studies have illustrated their benefits on student learning. For example, Squire and Barab illustrated that simulation games helped students increase their knowledge of history, politics, and geography [5]. Meanwhile, Liu et al. analyzed how students improved their computational problem-solving skills [20]. Castronovo et al. found that students improved their project management skills through the use of interactive construction games [4]. Wang et al. evaluated how games allowed students to solve complex business problems [21]. Lastly, Castronovo et al. developed an educational game to teach incoming freshmen students on proper waste management on campus [22]. Many other examples can be listed to illustrate the impact that educational games can have in higher education, and together with VR such benefits can be enhanced by directly immersing students in interactive environments.

2.3 Interactive and Immersive Classrooms

With the implementation of innovative technology in the classroom, instructors have changed how such spaces are designed. Tablets, desktop and laptop computers, and interactive boards are being utilized and evaluated in the classroom at a growing rate [23]. As VR grows in its adoption, the classroom infrastructure will have to adapt to the inclusion of large display systems and head-mounted display systems. This inclusion will transform the classroom into not just an interactive space, but also an immersive space. The use of immersive technology such as large interactive display systems has already shown value in the engineering industry, where interactive workspaces have become widely diffused [24]. Interactive workspaces can be defined as spaces that are infused with a wide variety of media, whose goal is to support the interaction between users and enhance problem-solving and collaboration [25]. In particular, these interactive spaces have the benefit of leveraging immersive display systems, either at a room or individual scale [26]. The benefits of these interactive spaces have started to trickle down to the classroom. For example, the Architectural Engineering department at Pennsylvania State University has been leveraging immersive display systems not only for research in professional applications but also for academic purposes [27], [28]. In their research, Castronovo et al. found that students were able to perform collaborative problem-solving sessions by leveraging immersive display systems as a classroom and learning space [28]. In their research, Kandi et al. found that students were able to improve their design evaluation skills by using over 10 VR headsets at large-scale in a class of 40 students [13]. Liu et al. used mixed-reality experiences to teach basic science concepts on the solar system at a classroom level [29]. Their study showed

that students found usefulness in the implementation of mixed-reality technology. These are just a few examples of the use of innovative technology in the classroom and, with this paper, the authors document their journey in designing and developing an Engineering course that uses such pedagogical methods and strategies.

3. Design of the Introduction to Engineering Course

3.1 Activities

To determine the potential that VR has on transforming the culture of learning in engineering at a curricular level, Cal State East Bay and Mission College, started the leveraging of such technology in Fall 2019. The two institutions collaborated on the redevelopment of their Introduction to Engineering and Design courses to include a variety of games and VR experiences. The schools designed their new version of the course by including five VR experiences and two desktop educational games (Table 1). The team developed instructional material for all of the games that did not include it. For those games that included instructional material, the team changed it to best suit their needs.

The first activity was designed around the VR game *Keep Talking Game*; the game "*is a video game [that] tasks the player with disarming procedurally generated bombs with the assistance of other players who are reading a manual containing instructions*" [30]. This game was aligned with the Teamwork lecture topic, and the learning objectives were that the students need to be able to describe and apply efficient team communication strategies. Together with the game, the research team developed activity instructional material to facilitate the implementation of the game. During this activity, the students are grouped in pairs and are challenged to solve puzzles in VR. However, only one student can wear the headset, while the other has a manual with the solution to the puzzle. The students need to communicate with each other to solve the puzzle. At the end of the VR game, the students need to reflect on the challenges that they encountered and how they can improve their team communication.

To support the Project Management lecture topic, the *Virtual Construction Simulator 4 (VCS4)* game was selected. The game is "*a simulation game that teaches students the dynamic nature of the construction process and frequent changes to construction schedules*" [31]. The game was selected because of its extensive supporting instructional material. In this activity, the students follow the instructor in planning and managing the construction of a woodshed. The students need to select the construction methods, develop a sequence of construction, and deal with the factors that slow down construction, such as weather, poor sequencing, and the fatigue of workers. During the activity, the students need to reflect on the factors that slow the construction and identify ways to increase the efficiency of their plan.

For the Truss Building laboratory, the team developed a hybrid activity that involved the use of the *PolyBridge* desktop game and the use of popsicle sticks. The activity challenged the students to develop a popsicle truss bridge for a provided problem and test their prototype on the *PolyBridge* game. The game "*is a bridge-building simulation-puzzle game [...] where players*

build bridges for vehicles to cross" [32]. This activity was designed especially for the departments that do not possess a load-stress machine to test the students' prototypes.

Table 1: Activities Alignment to Class Lectures and Labs

LECTURE OR LAB TOPIC	ACTIVITIES	MEDIUM	LEARNING OBJECTIVE	LINK
Teamwork Lecture Topic	Keep Talking Game	VR	1. Describe efficient team communication strategies 2. Apply team communication strategies	https://keeptalkinggame.com/
Project Management Lecture Topic	Virtual Construction Simulator 4	Desktop	1. Explain concepts of project scheduling 2. Create project management plans 3. Evaluate scheduling choices and factors	https://psu.box.com/s/79h0o2yosbb25bk1ggzionus9o5mzdgk
Truss Building Laboratory Activity	PolyBridge	Popsicles and Desktop	1. Construction prototype bridges with popsicles 2. Apply forces on a bridge in a simulated environment 3. Evaluate factors and forces applied to a simulated bridge	https://store.steampowered.com/app/367450/Poly_Bridge/
Engineering Method and Graphics	Design Review Simulator	VR	1. Identify the different types of design mistakes 2. Define the provided design mistakes 3. Evaluate proper construction methods	https://drive.google.com/file/d/19SlQr--yuaeNkg6VQit0lx20tAYXj0pm/view?usp=sharing
Reverse Engineering Lecture Topic	Wrench: Engine Building Demo	VR	1. Identify the main components of a power engine 2. Describe the power generation process	https://www.oculus.com/experiences/rift/1755851804523719/?locale=en_US
Introduction to Civil, Electrical Engineering Discipline Lecture Topic	Hoover Dam: Industrial VR	VR	1. Identify components of a hydropower plant 2. Describe the power generation process 3. Evaluate the environmental impacts of hydropower plants	https://www.oculus.com/experiences/rift/1297777480332012/?locale=en_US
Introduction to Environmental Topics	Attack of the Recyclops	VR	1. Identify the different types of trash bins 2. Match the symbol/label to the correct trash bins 3. Explain the importance of properly choosing the correct waste stream.	https://www.fadicastronovo.com/research-groups/stem-educational-gaming-research-group

The team also chose a VR educational game that was designed at their own institutions. The *Design Review Simulator (DRS)* was designed by students of Mission College with guidance from Cal State East Bay. The learning objectives of the game are to support students in developing evaluation and reviewing skills of mistakes in construction projects through the use of VR. The researchers designed and developed the game in the Unity 3D game engine [6]. The

game comes with learning assessment and instructional material to easily implement it in a course. This game was aligned with the Engineering Method and Graphics lecture topic. In this lecture, the design process is covered, and the students are asked to begin developing their prototypes with SketchUp. The game was chosen to support the students' understanding of the value that 3D modeling tools and VR have in the design process. During the activity, the students need to identify design mistakes and reflect on the value that prototypes and concepts provide to the design process.

For the Reverse Engineering lecture topic, students are tasked with explaining the combustion engine cycle by reverse engineering part of a car engine in VR. The simulation chosen for this is the *Wrench: Engine Building Demo*, where "*players will work through assembling an inline four-cylinder engine. Wrench encourages players to explore and solve problems on their own.*" [33]. The purpose of this activity is for students to identify components of a power engine and describe the power generation process. The students are provided with a handout that requires them to summarize parts of the engine. The instructor then leads the students in a discussion of the engine's power generation process.

The game that was chosen for the Introduction to Civil and Electrical Engineering Disciplines lecture topic was the *Hoover Dam: Industrial VR*. The game "*takes players on an exclusive journey through the Hoover Dam. Fly overhead for a bird's eye view, pick any spot to land on and explore, or go inside the pipes and through the machinery to look into the heart of this technological feat with the highest level of access imaginable*" [34]. During the activity, students explore the Hoover Dam and identify and explain the parts of the dam as exposed in the game. The students are provided with an activity sheet where they have to report their findings. Additionally, the students must reflect on the benefits and environmental impacts of hydropower.

Lastly, the game designed by Cal State East Bay *Attack of the Recyclops* was chosen as it aligned to the Introduction to Environmental Topics lecture. The *Attack of the Recyclops*, is an educational game developed for first-year college students to learn how to properly dispose of waste, such as composting and recyclable materials, within a virtual model of a local college campus [22]. The game has shown potential in supporting students in learning proper waste management and developing strong environmental responsibility towards their campus. The game comes with an assessment instrument designed to evaluate the students' learning.

3.2 Design Challenges

In addition to the inclusion of the activities, the two institutions also developed three course projects that engage the students in developing new technology-based activities and connections to their curriculum and campus environment as part of their semester project. In these projects, teams of students learn to model in 3D and develop VR experiences that relate to various engineering problems. These projects include the development of a way-finding application for incoming students, designing a wind turbine for a farmhouse, and designing a solar farm for a campus parking lot. The following is the prompt for the third scenario, designing a solar farm for a campus parking lot.

"Your company (composed of 3 group members) has been hired by the president (your professor) of Cal State East Bay to develop a virtual reality prototype of a solar parking lot for your campus. This prototype will require you to survey your campus parking lots, research existing solar parking lots, and evaluate different types of solar panels and their structure. As part of the prototyping process, you will have to set objectives for your prototype and develop storyboards illustrating your concept. You will have to develop 3D models in SketchUp of your parking lot and use the Unity game engine to generate virtual reality walkthroughs and graphical user interfaces coded in the C# language. You will have to pitch your prototype at the end of the semester to the president of the university (played by your professor) through a professional PowerPoint presentation and well detailed written report."

The students complete these projects through several asynchronous laboratories and classwork. In particular, the students are challenged to engage in a series of video tutorials, developed by the instructors, to generate 3D models in SketchUp, navigate the basics of Unity and creations of Graphical User Interfaces (see Table 2). The students then test their prototypes in VR equipped laboratories.

Table 2: Online Tutorial Lecture Series

TOPIC	LINK
SketchUp 2018 Tutorial Series	https://www.youtube.com/playlist?list=PLoIkp3dSPsS3m7l_5JL09UZACuRcx8X06
Unity Basics Tutorial Series	https://www.youtube.com/playlist?list=PLoIkp3dSPsS3mRvyQJk9DXAf49n2mqNaL
Unity UI Tutorial Series	https://www.youtube.com/playlist?list=PLoIkp3dSPsS0NRnvDI2KrIKGnQRAxM-7h

Each of the three design challenges is broken into three major submissions. The objective of the first submission for the students to describe their process in evaluating user needs, setting objectives for their prototypes, and developing concepts through storyboards. The following is the prompt for the first submission of the third scenario.

"The President of the University, as a first submittal, wants to perform a detailed survey of your campus parking lots, research existing solar parking lots, and evaluate different types of solar panels and their structure. You will have to develop objectives for your prototype game, choose what virtual reality system will be used, etc. You will also have to start the design process of the prototype. The objectives are up to you, but they have to be related to supporting the campus through renewable energy, so let your creativity flow. In particular, you will have to design the user experience and interface by generating storyboards. For this submittal, you will have to submit a report of this first stage of prototyping, including full descriptions and scans of your storyboards."

In the second submission, the students need to address any feedback provided by the professor from the first submission. In addition, the students need to develop 3D models of their panels chosen during the conceptual phase. The students need to create the models in SketchUp with a high level of detail. The following is the prompt for the second submission of the third scenario.

"After the development of the storyboards and faculty feedback, you must complete the 3D models of the parking lot from your campus and solar panel structures with the use of SketchUp and Google Earth Pro. You must have one high-detailed solar panel structure per team member. For this submittal, you will have to update your previous report with the feedback given to you by the professor. You must add to your previous submission screenshots of the panels that are you are going to use in your prototype. You must add to the document that you have created in Submission 1 screenshots of the buildings. You must add at least 3 screenshots per panel."

For the last submission, the students again need to address any feedback provided by the professor from the first and second submissions. Lastly, the students need to develop graphical user interfaces (GUI) in Unity using the C# coding language. The purpose of this GUI is for future users to learn about the students' prototype and evaluate the most optimal solution. The following is the prompt for the final submission of the third scenario.

"For this submittal, you will have to add to develop a virtual demo of your prototype and screenshots of the graphical user interface (GUI) that are you are going to use in your prototype. You must add to the document that you have created in the previous submission, the screenshots of the GUI. You must add at least 3 GUIs per building. Each team member must create a playable version of their solar parking lot with at least 3 GUI elements. You will also have to write a final conclusion section of the report."

Table 3: Activities and Assignments Alignment

LECTURE TOPIC / LABORATORY	ACTIVITY AND ASSIGNMENT SUBMISSION
Introduction to Virtual Reality / Environmental VR Experience	**Activity** #5 Applications of VR Reflection
Introduction to Engineering Design / Design of Swimming Bag / IDEO Shopping Cart	**Activity** #6 Prototype Brain-Storming
User-Centered Analysis / User Interview Survey Development	**Activity** #7 Prototype User Analysis
User-Centered Design Part 1 / Objective Setting / Smart Goals	**Activity** #8 Prototype Objectives and Goals
User-Centered Design Part 2 / Storyboarding	**Activity** #9 Prototype Storyboards
How to Present / Improv. Selling	**Activity** #10 PowerPoint Prep
Early Prototype Presentation	**Activity** #11 PowerPoint Pitches
Introduction to Project Management / Scheduling in Microsoft Project	**Assignment** Prototype Submission 1
Introduction to Sketch UP	**Activity** #12 Sketch UP In-Class Activity
Sketch UP Lab 1	**Activity** #13 Sketch UP Concepts
Sketch UP Lab 2	**Activity** #14 Sketch UP Concepts 2
Project Management Virtual Construction Simulator 4 Scheduling Experience	**Assignment** Prototype Submission 2
Introduction to Unity Basics	**Activity** #15 Unity Basics Screenshots
Introduction to C# Coding	**Activity** #16 Unity GUI Scripts
Introduction to GUI Development	**Activity** #17 Unity GUI Screenshots
Finals	**Assignment** Prototype Submission 3

Each of the design challenges is broken into three submissions in order to adopt a continuous improvement approach to the assessment of students' performance. By breaking the design challenge into three submissions, the students are able to receive early feedback on their assignments and address any necessary changes. This method allows the students to improve their performance in the course and achieve higher grades as they are able to perfect their projects by the end of the semester. In addition to breaking the challenges into three submissions, several of the courses' activities are aligned to the submissions, making the students get further feedback before they submit each submission (Table 3). As the students work on their activities, they are putting together building blocks for their submissions. This allows them to get fast

feedback from the instructor and reduce stress during finals week. For example, during activity 7 and 8, the students need to perform an analysis of the users of their prototype and develop goals for their project and prototype use. The students then need to submit a written reflection on their work. This allows the instructor to evaluate their understanding of the analysis process and make sure that they developed strong goals. Furthermore, this will ensure that the students are on track to submit their first assignment.

4. Design of the XR Lab

The development of an interactive classroom and workspaces requires the instructor to think of the following factors: space, group size, and use case [24]. According to Castronovo's Interactive Workspace Decision Map, in order to select the appropriate technology in an interactive workspace, the facilitator/instructor must look first analyze the size of the space that they are working with [24]. The authors of this paper decided to work with a large space, in particular, an engineering classroom at Mission College. The classroom would be renamed to the Reality Laboratory (XR Lab). The XR Lab can host a total number of 36 students, all with their dedicated desk integrated with a desktop computer and retractable screen. Based on the available space, the authors, according to the decision map, had to select the size of the group that they wanted to target during their instruction. As the authors wanted to maximize the impact of their innovative curriculum, they selected a large size of the audience for their interactive workspace. Next, the authors had to decide what use cases did they want their audience to be engaged with. Since the *Introduction to Engineering* challenged the students to generate, visualize, and analyze their designs for their final projects, the authors selected the *Design Charrette, Design Review,* and *System Review* use cases. The Interactive Workspace Decision Map provided the authors with an appropriate technology list to accomplish their desired use case. This list gave a chance for the authors to choose equipment that ranged in cost. As the budget of the authors was limited, they opted for the lower-cost equipment. In addition to the decision map, the team relied on their previous experiences in leveraging and designing interactive spaces. For example, Cal State East Bay has been performing large-scale VR activities since early 2016 by retrofitting an existing computer laboratory, the Visualization and Immersion Classroom (VIC). The VIC is suited for the delivery of large-scale group-based educational interventions (see Figure 1). The VIC is a computer laboratory equipped with 10 high-end VR computers and 10 VR headsets. The participants in these pictures have provided IRB approval.

Through the Interactive Workspace Decision Map and their previous experiences, the authors selected the equipment listed in Table 3 for the XR Lab. As the classroom that was selected already had computer LED screens, no additional screens were bought. The team selected to purchase Oculus Rift S headsets as they provided the necessary visualization requirements for their planned activities, versus the Oculus Go, which wouldn't have been powerful enough. The Oculus Rift S was selected over the HTC Vive Cosmos as the authors did not plan for large room VR experiences but instead wanted to focus on sitting experiences. Additionally, the HTC Vive Cosmos did not meet the budgetary restrictions. The team opted for purchasing both laptops and desktops in order to run their activities. This would allow them to run group activities with the desktops, where students would work together in pairs for a total of 32 students having a VR experience. The laptops were purchased to allow instructors to leverage

the technology in other classrooms as needed. In order to house the new desktops, the authors had to modify the desks. This did increase the cost of the implementation, but it was within the budget.

Figure 1: Visualization and Immersion Classroom (VIC) at Cal State East Bay

Table 3: XR Lab Equipment List

Equipment	Number of Equipment
Oculus Rift S	16
Alienware m17 Laptop	16
Alienware Aurora R8 Desktop	16
USB Splitters	16
Mice	16

5. Implementation Lesson Learned

In the Fall of 2019, the authors from the two institutions had successfully implemented three of the VR activities and engaged students in one desktop activity (see Figures 2 and 3). The games and VR experiences were chosen for alignment with the course modules' topics and learning objectives. The team developed learning, teaching, and assessment material to integrate the activities into the course. The activities implemented were: *Virtual Construction Simulator 4*, *Design Review Simulator*, and the *Keep Talking Game*. Based on early applications, the authors identified several lessons learned for future implementations in the form of time structure for the activity, illustrated in Table 4. Before the activity can be implemented, it is essential for the instructors to introduce to the students the necessary concepts. For example, for the lecture topic on *Project Management (PM),* the students are lectured on concepts of project scheduling, work breakdown structure, predecessors, and successors. Before the instructor can get the students started, it was necessary to check that the software and hardware worked on all of the computers. Additionally, the instructor had printed all of the instructional material handouts for the students to complete the activity. For the PM topic, the class was challenged to play the *Virtual*

Construction Simulator 4, which challenged the students to develop and simulate a construction schedule and evaluate the factors that slow down construction (see Figure 2). The participants in these pictures have provided IRB approval. Before students can play the VCS4, the instructor must remind students of previously presented concepts. This is necessary to activate the students' memory and prior knowledge.

Table 4: Activity Structure

- Class before activity
    - Lecture on concepts to be introduced
    - Give pre-test during class time (10 minutes)
    - Outside class time run all of the equipment and software the day before to test that everything is running smoothly.
    - Print all necessary handouts
- Class of activity
    - The instructor welcomes students
    - The instructor breaks them into groups of 2
    - Students are not to begin using the VR headsets or games until instructed to do so
    - The instructor introduces activity (15-20 minutes)
        - Perform a Mini-Lecture
            - Refresh on concepts from the previous class
        - Demonstrate the activity
            - Instructor pairs up with a student and performs part of the activity while the rest of the class observes
    - Students perform group activity (30-35 minutes)
        - Design activity so that students shuffle between wearing a headset and taking notes
        - Instructor and assistants walk around to facilitate and answer questions
            - Note: if any group is much faster (and correct) then have them proceed with doing extra
        - Don't go beyond 35 minutes inside VR headsets as students tend to get motion sickness
    - Post-activity discussion (20 minutes)
        - Have each group write a reflection on the activity
        - Have an open discussion on students' experience and learning
    - Give post-test (10 minutes)

The next step is for the instructor to break the class into groups of two, as indicated by the instructional material, and to allow students to work in a group problem-based environment. The authors found that engaging the students in paired group activities allowed for the students to collaborate and supported them in taking notes or complete any instructional material (see Figure 3). The participants in these pictures have provided IRB approval. Before the students can get started, it was found that the instructor must perform some "role-play" with the students and demonstrate how to perform the activity. For example, with the *Design Review Simulator*, the instructor can pair with a student, wear a headset, and play the game with a student for a few minutes and instruct his/her/their teammate to write on the activity handout (Figure 1). During the role-play, the instructor invites the rest of the class to look at his/her/their group so that they understand the logistics of the activity. After the role-play, the instructor lets the students get started with their activity. During the activity, the instructor, and if available, their assistant must walk around continuously to ensure that any questions from the students are answered. For the

VR activities, the authors found that limiting the gameplay to 35 minutes avoided the students from suffering from motion sickness. At the end of the activity, the students must reflect on their activity. The authors found that the reflection can be structured by first getting the students to write on their handouts and then having an open discussion. In case the instructor wants to collect any research data, the pre-test is suggested to be given the class period before the activity and the post-test be administered right after the activity has ended. While these lessons learned were collected from early implementation, the authors believe that they are of extreme value not only for their own future applications but also for other instructors that are interested in using VR in their classes.

Figure 2: Cal State East Bay Students Playing the *Design Review Simulator*
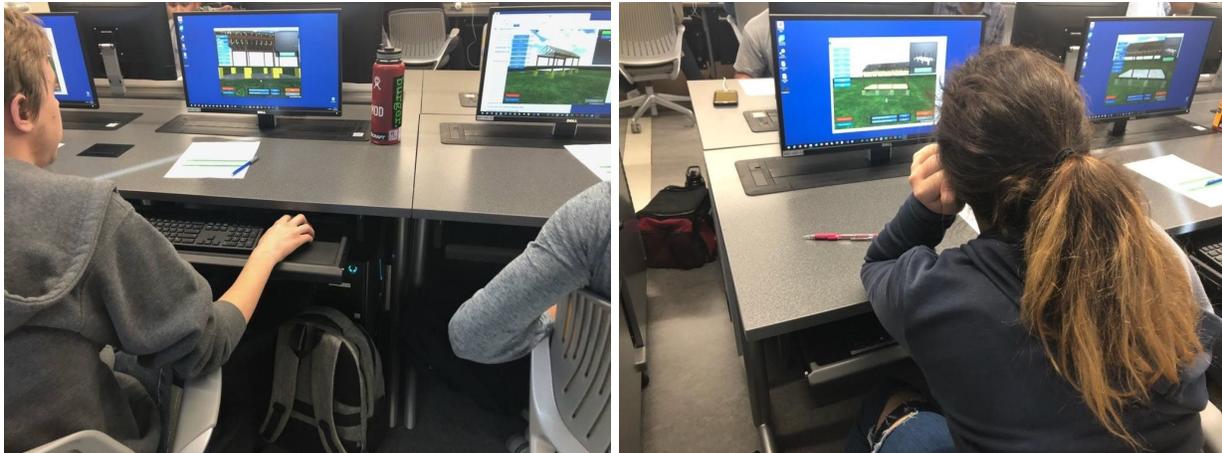
Figure 3: Mission College Students Playing the *Virtual Construction Simulator 4* at the XR Laboratory

6. Conclusion

Cal State East Bay has implemented a pilot version of the course in the Summer of 2019 as part of their Virtual Reality Engineering Summer Camp (VRES Camp), sponsored by the Broadcom Foundation. The VRES Camp served students from the Hayward High School District, and it included several VR experiences. The high school students were engaged in a "light" version of the VR Campus Way-Finding App project challenge. Early assessment of the

camp's impact illustrated that the students, most of whom had very limited experience with engineering design, were able to achieve the camp objectives and were strongly engaged with the technology and course activities. The VRES will also be hosted at Mission College in the Summer of 2020. Similar to the VRES, the Cal State East Bay faculty has implemented a VR design challenge in their ENGR 400A Historical Architectural Virtual Prototyping, a study abroad course in Italy. In the challenge, students had to develop interactive virtual prototypes of historic architectural buildings. Using innovative technology, students supported historic preservation efforts and enhanced community understanding of historical architecture.

Due to these successful pilot implementations, the next step in the research will be to evaluate the value of this curricular design. In the Spring of 2020, the authors will begin to evaluate the impact of the inclusion of this technology on students' learning as it relates to their self-efficacy, motivation, degree of engagement, and sense of belonging. The evaluation plan will entail a series of pre-test and post-test experiments. All students will receive pre-test material based on the dependent measures, which include self-efficacy, motivation, degree of engagement, and sense of belonging. These measures have already been constructed and validated and will provide a baseline. The authors aim at using the surveys developed by the Lawrence Hall of Science (LHS) Activation Lab [35]. Finally, a qualitatively-based exit questionnaire will help the authors understand how students feel about the coursework, with a focus on how the team can improve. IRB approval has been provided to perform these studies.

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