ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37447

Work in Progress: Design and Development of an Immersive Virtual Reality Educational Game for Wind Power Education

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Abstract

In this paper, the research team will discuss the lessons learned from the design and creation of an Immersive Virtual Reality (IVR) serious game intended to enhance the teaching of a Wind Turbine lab in an Introduction to Engineering class at a community college. The serious game was designed and written by four students at the community college as part of a summer research project under the leadership of two professors from two institutions: a community college, and a university. The students learned storyboarding, SketchUp, and Unity and applied these tools to create the serious game from scratch. In the serious game, future students will be able to engage in an immersive virtual reality environment, reinforce power equations discussed in class, and adjust the parameters of the wind turbines themselves to see the resulting power through a numeric display and the amount of light generated. The goal of this paper is to share the design choices and development of the IVR serious game for use in an Introduction to Engineering virtual classroom to enhance the teaching of wind energy conversion. Learned lessons will be shared to support other instructors that are planning on pursuing similar research and/or implementing innovative technology in their courses.

1. Introduction

In recent years, Virtual Reality (VR) has become a more common platform to use in classrooms to enhance pedagogy. Many former researchers have used VR to help their students understand previously hard-to-grasp concepts and increase enthusiasm in classrooms based on the VR modality. The work described in this paper was built on this idea and strived to create an Immersive Virtual Reality (IVR) educational serious game where Introduction to Engineering students at Mission College (a community college in Santa Clara, CA) could design full-scale simulated wind turbines. These students could then see the impact of their design choices through the representation of modeled turbines and the corresponding illumination of a campus park based on the calculated conversion of wind energy to electrical energy. The design and development of this work was done in large part by four Mission College students over the summers of 2020 and 2021 and advised by two faculty members, one from Mission College and one from the University of Brighton.

This paper sets the stage by first reviewing advancements in educational gaming. Next, previous VR classroom applications and the associated research is discussed. The third and final section of the Literature Review looks at motivations and strategies in teaching students about harnessing and converting wind power. The remainder of the paper covers the design process, analysis, and development of the IVR simulation itself. Screenshots of the scenes within the serious game are provided to give context for what students experience when interacting with this simulated tutorial.

2. Literature Review

2.1. Educational Gaming

In recent times, more and more researchers and educators are seeking to innovate their teaching in ways that are easier for students to gain skills and knowledge, and one popular method is educational gaming. Educational serious games are games that have either been intentionally designed for the purpose of education, or those entertainment games that have incidental or educational values [1]. Educational serious games are designed to help people understand concepts and learn domain knowledge [2], [3]. Furthermore, educational serious games, if designed appropriately and in accordance with the learning objectives, can stimulate students' critical thinking, problem solving, collaborative and emotional learning, and risk-taking [4]–[6]. Educational serious games also enable the student to interact with a repeated environment suited individually for them [7]. Research shows that educational serious games that allow players to emulate a certain role provide motivation in learning the mastery of that role, thus laying a strong foundation of that player's knowledge [1]. Research also shows that educational serious games with the necessary amount of freedom allow for growth in problem identification, hypothesis testing, interpretative analysis, strategic thinking, and environmental consciousness [8], [9]. Educational gaming has also shown success in information retention in fields that would not conventionally use serious games for learning, such as the medical field [10]. Additionally, educational gaming has seen a surge in popularity in the engineering field as educational gaming works synergistically with engineering principles of problem-solving and critical and creative thinking [11], [12], [13]. One way to provide educational gaming is through virtual reality, as it enhances the player's spatial and physical presence through its technology.

2.2. Virtual Reality and Education

Virtual reality is a medium that promotes a greater sense of spatial immersion for educational gaming as the technology creates a virtual, simulated environment. Immersive virtual reality leverages computer technology to create a simulated environment in which players are immersed through 3-Dimensional (3D) and sensory interaction [14]. IVR gaming is especially helpful in educational fields that require simulations or 3D simulations as it provides a heightened sense of immersion that traditional education cannot provide [15], [16]. Tideman et al. and his research team showed that IVR gaming encourages players with a variety of skills and improves design development [17]. The researchers were able to create a rich, social IVR gaming experience that required players to interact with other players. This type of interaction intrinsically creates an engaging virtual environment that includes the social aspect of a traditional classroom while also demonstrating an immersive experience through the IVR medium [17], [18]. IVR gaming can be supplemented with even more immersive technologies such as gesture armbands, motion sensor devices, and foot pedals. One researcher used such devices for injury rehabilitation for stroke survivors [19]. IVR simulation also showed positive results in research that tested for motor skills and rehabilitation for cognitive deficits in patients with brain injuries [20]. Research also showed that math skills can be improved when using simulation-based serious games through IVR [21]. With recent releases of low-cost IVR hardware, IVR provides satisfactory results when trying to stimulate patients' cognitive and motor functions [22]. In this paper, the authors were interested in investigating the impact that an IVR educational serious game has on teaching concepts of the conversion of wind power to electrical power.

2.3. Wind Power Education

Renewable energy is quickly becoming a priority to address climate change and sustainability goals set by the United Nations [23]. With a focus on renewable energy, wind power is becoming more affordable to produce and, by broadening the understanding of the benefits of wind power, one can hope that its adoption will continue to rise. At the University of Vaasa in Finland, two wind turbines have been installed for educational and research purposes. This energy facility provided learning and research opportunities for students which led to making the wind turbines more efficient [24]. Simulations used in online classes at the Technical University of Denmark gave a realistic insight into the interaction between wind farms and power transmission systems [25]. Similarly, researchers in Korea created a wind energy education program using data and analysis that led to the development of demonstrations of renewable energy [26]. In China, researchers have emphasized wind energy education, as the nation's wind power industry is rapidly growing due to the demands of climate and its national economic growth [27]. Research in Sweden shows that educators, businesses, and industrial administrators are actively working to raise awareness in wind education to provide necessary schooling for the wind industry [28]. To enhance students' understanding of the benefits of wind power, the authors wanted to share an experience in developing an IVR educational serious game, the *Virtual Reality Turbine Simulator* (VRTS), focused on teaching concepts related to wind power and wind turbine design.

3. Instructional Design

The authors designed and developed an IVR educational serious game to support an Introduction to Engineering lesson related to the conversion of wind energy to electrical energy. In the traditional lesson and corresponding activity, students in the class would design their own miniature turbines, attach them to motors, hold them in front of a large fan, and measure the generated voltage and current. The wind energy equation $P_{wind} = 0.5\rho A v^3$ (where ρ is the air density, A is the swept area of the turbine, and v is the velocity of the wind) is emphasized the fact that the swept area of the turbine can increase the wind energy being captured. The wind energy captured by the turbine $P_{captured\ wind} = P_{wind} * \eta$ (where η is a catch-all efficiency parameter that incorporates many factors). The remainder of the lesson comes with understanding the large losses that come from the conversion of the captured wind energy, $P_{captured\ wind}$, and the electrical power, $P_{electrical} = VI$, found by multiplying the measured voltage, V, and current, I. While this classroom exercise gets some of the points across, the sheer magnitude of useful wind turbines are still hard to grasp. The serious game was developed, in large part, to help undergraduate college students see how different wind turbine design choices would impact the generation of power with full-scale turbines. The serious game was developed to run on the Oculus Rift S virtual reality headset. The serious game immerses the learner in a virtual environment where they can walk around and experiment with different wind turbine elements, such as the number of blades, the length of the blades, and height of the turbine. The serious game development was influenced by the ADDIE model framework for instructional design, created by the Center for Educational Technology at Florida State University for military training and has become a commonly used model for instructional design [29]. The acronym ADDIE stands for different iterative instructional design phases: *analysis, design, development,* *implementation, and evaluation* [30]. The following subsections describe the *analysis, design,* and *development* of the serious game.

3.1. Analysis

The serious game was designed to support Introduction to Engineering students with two main goals: (1) enhance the wind energy lesson where students design wind turbines and (2) to expose students to virtual reality. As such, the serious game was designed to be played in a laboratory setting equipped with VR equipment.

Using the Revised Bloom's Taxonomy [31], the development team focused on a range of both lower and higher-order cognitive thinking skills of identifying, remembering, understanding, analyzing, and evaluating (Table 1). The main objective of this serious game was to teach and explain how the wind turbine efficiency equation was affected by different simulated parameters (Table 2). The learning objectives dictated how the serious game was designed in terms of the virtual environment, controls, and user interface. The serious game also simulates the efficiency of three wind turbines with variable design features, which include the turbine's height, the number of blades, wind speed, and blade length, and its active state.

Table 1. Structure of the *Virtual Reality Turbine Simulator*

Cognitive Domain	Action Verb	Seirous Game Learning Objective
Remembering	Identify	• Identify variables of a wind power equation
Understanding	Define Summarize	• Define the different variables of a wind power equation • Summarize the different parameters that influence wind turbine design
Analyze	Differentiate Select	• Differentiate between different parameters that influence wind turbine design • Select the parameters for optimal wind turbine design
Evaluate	Test	• Test different parameters that influence wind turbine design

Table 2. Variable Parameters.

Parameters	Changes in the equation for captured wind power: $P_{captured\ wind} = 0.5\rho A v^3 \eta$
Wind Speed	v, wind speed changes directly
Blade Length	Calculated swept area, A, is dependent on blade length
Height	ρ, air density changes with altitude

Blade Number	η, the number of blades have been found to impact efficiency
Turbine type	Total Power

3.2. Design

With well-defined learning objectives, one can start designing the serious game structure and mechanics. The structure of the serious game was storyboarded to design the necessary graphical user interfaces (GUIs) and ways that the learner will interact with them (Figure 1). The aesthetics of the serious game were guided by previous research in multimedia learning, in particular Richard Mayer's cognitive theory for multimedia learning [32]. In particular, the authors wanted to allow for the learner to integrate multiple types of media (verbal and visual) without overloading them.

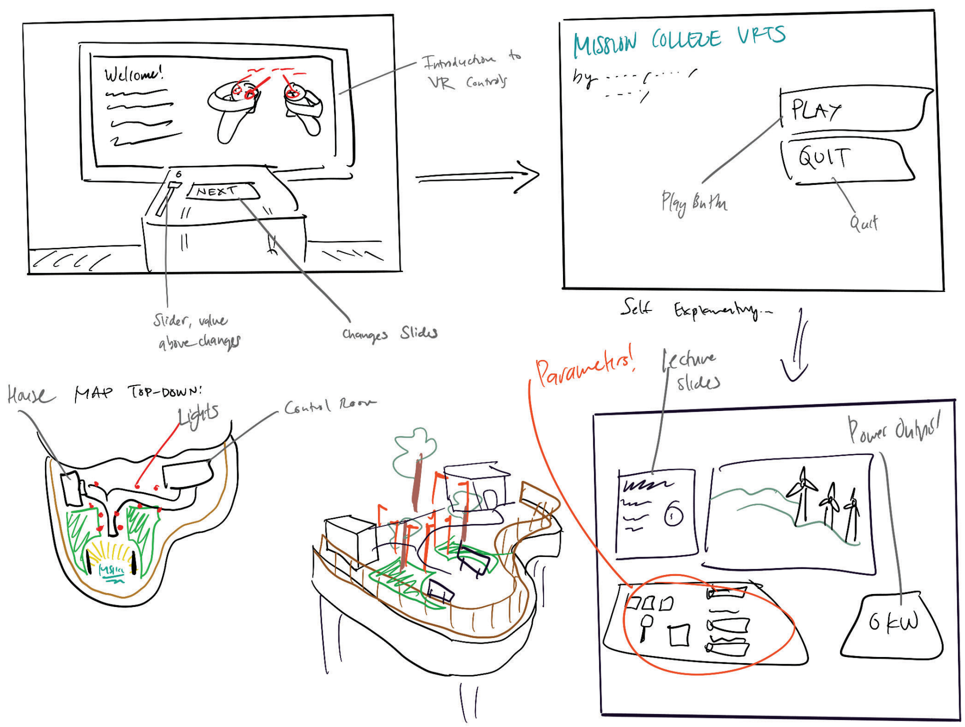

Figure 1. Serious Game Storyboarding

Based on the storyboards, the serious game was then structured to have three scenes, as seen in Table 3, and a linear game mechanic, as seen in Figure 2. The first Interaction Tutorial scene (Figure 3) takes the learner through a tutorial on how to interact with the game interface while in VR. This scene has introductory GUI panels that provide explanations of the VR environment and available buttons. The Interaction Tutorial's GUI panels are buttons and sliders that function as a space for the learner to practice interacting with the environment without affecting the serious game.

Table 3. Serious Game Structure

Serious Game Scene	Serious Game Mechanics	Purpose of Scene
VR Tutorial	● Start Game ● Introduce to VR environment ● VR GUI - Buttons, Sliders, Slides	● Start the Game ● A test run for VR Calibration
Main Menu	● Start and Quit button	● Menu to start/quit game
Main Game Scene	● Read instruction ● Turn on wind turbines ● Change parameters ○ Height, number of blades and its length, air speed, # of turbines ● Change lighting based on power output	● Introduce player to the turbine efficiency equation ● Allows player to change parameters and see real-time changes on lighting environment (lighting) ● Teaches effect of change in parameters in the equation

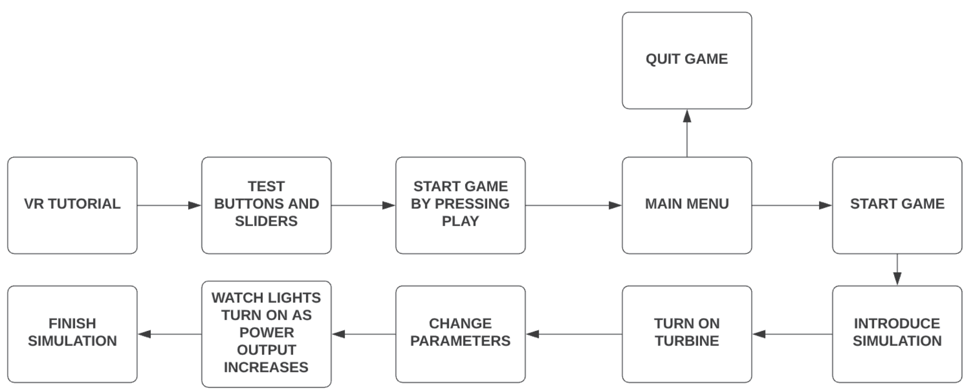

Figure 2. Game Mechanics

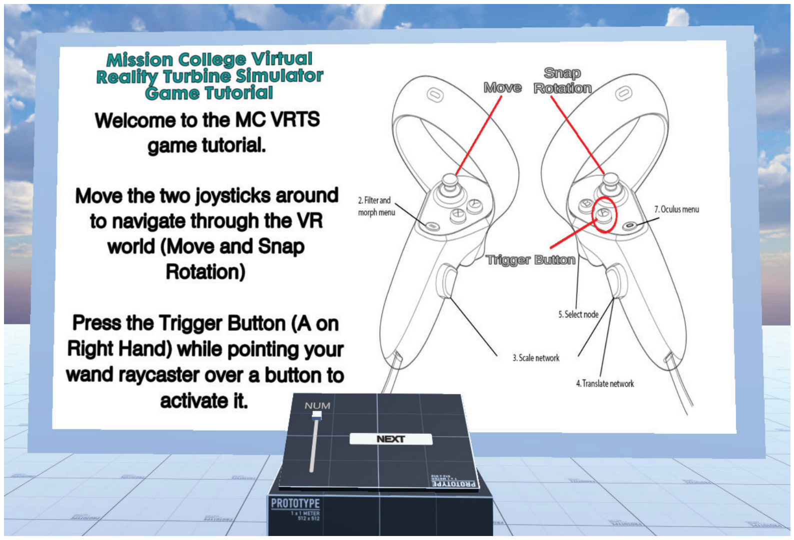

Figure 3. VR Tutorial Scene

Once the tutorial is completed, the learner is transported to the Main Menu scene. In this scene, there are two buttons, Play and Quit, as seen in Figure 4. The Play button transports the learner onto a simulated community college campus park (Figure 5), and a GUI panel introduces the task of lighting up the park. The learner is given a chance to explore the park and is led to the control room (Figure 6) where the simulation controls are located. The learner is able to adjust the *active state* (on/off) for three turbines, the wind speed, and each turbine's number of blades, blade length, and height. The learner can freely check if the park's lights are being powered by the energy harvested from the turbines. The lights of the park change in their intensity based on the different turbine designs proposed by the learner. The serious game is designed to provide a chance to experiment with the wind turbines' design, thus having no discrete winning or losing conditions.

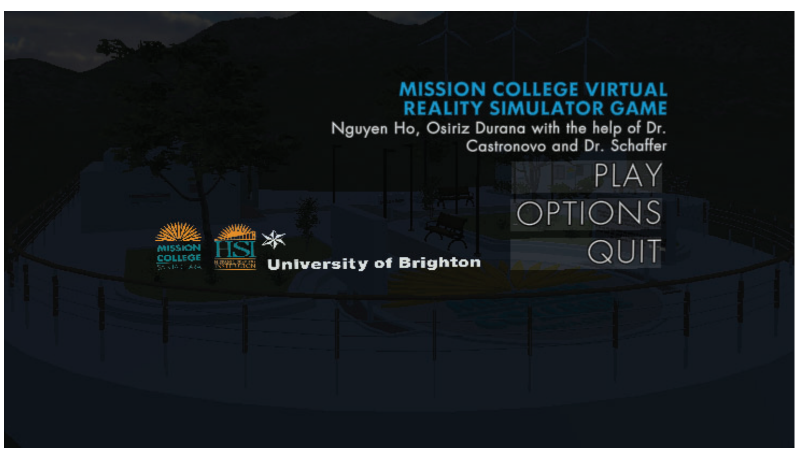

Figure 4. Start Screen

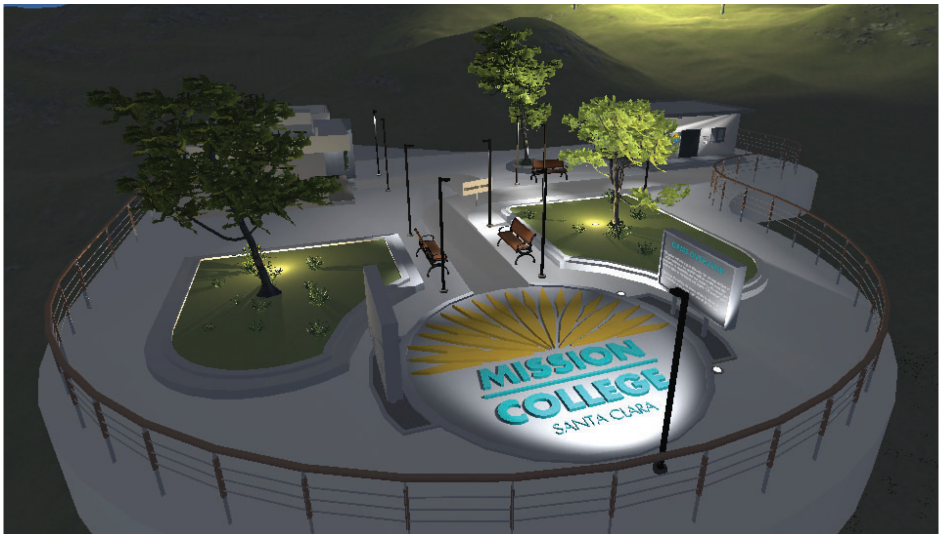

Figure 5. Campus Park

Figure 6. Control Room

3.3. Development

The authors chose the Unity game engine for the serious game's development because it has a development plugin for the Oculus platform and because it includes easy tools and workflows to generate GUI elements. Additionally, Unity supports publishing the game for multiple platforms, such as Windows and Macs. Unity also has a powerful rendering engine that allows multiple types of 3D model files to be imported. The 3D models of the park, control room, and wind turbines were designed in SketchUp and exported as Collada files. At first, the authors discussed the idea of making the game into a regular keyboard-and-mouse, but instead, the Oculus controls were chosen as the primary mode for user interaction to include the goal of exposing introductory students to virtual reality. The coding language that the authors used for the game was C#. The authors used an Oculus Rift S headset to test the serious game. The scenes were developed in the order they were described and shown above: the VR tutorial scene, followed by the Start Screen, then the Campus Park, and the Control Room. All the while, the learners can see the impact of their design choices on the turbines by observing the turbines themselves as seen in Figure 7. Once the serious game development was completed, the game was then exported as a Windows Executable file.

Figure 7. Wind Turbine Farm

4. Conclusion and Future Work

While the bulk of this work was concluded in August, 2021, new features and refinements continued through Fall 2021. Since the targeted Introduction to Engineering class was online in the Fall, the first opportunity to use this in the classroom will be in the Spring 2022 semester. Future work will include having students actually using this as part of their Wind Turbine lab assignment and observing how students engage with the material. Students will be observed to learn more about engagement levels and enthusiasm, understanding of material, and retention of material as compared to previous classes that only (1) discussed this in the scaled down version of the lab or (2) only performed the analysis based on data that former in-person teams had collected. The students' interaction with the serious game will also be observed to identify areas where the serious game can be improved. The team hopes to continue this research over the Summer of 2022 where two new community college students can learn useful skills and help enhance the program for future use.

5. Acknowledgements

This research was funded by the HSI-STEM grant at Mission College. The authors thank Luis Morfin and Melissa Rivera for their work on this project during the summer of 2020 and Nguyen (Dang) Ho for his work on this project during the summer of 2021.