Web-based Game vs. Virtual Reality Field Surveying Labs Towards Enhancing Experiential Education

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Abstract

Introductory surveying engineering courses include several outdoor labs that introduce students to proper use instruments and equipment. Through practice and experiential learning students develop technical skills and learn about surveying techniques and methods. In addition, through review and reflection of their surveys, students are able to reinforce concepts learned in lectures. Outdoor labs have several challenges such as being affected by weather leading to cancellations that disrupt the educational process. Moreover, the COVID-19 pandemic has introduced new challenges and forced virtualization of outdoor labs. Development of virtual and immersive technologies in the past decade have sparked applications in engineering education, offering viable alternatives, and enhancing traditional instructional approaches. Indeed, virtual reality and gamification technologies offer different learning approaches while various learning outcome can be achieved. In this paper two promising approaches, Web-based game and virtual reality, for virtualization of experiential educations and remote field delivery have been investigated. This study uses data collected in different institutions but in similar introductory surveying courses. The first dataset is from civil engineering students who used a game-based Web application to simulate topographic surveying. Being a game-based implementation, emphasis is placed on following best field practices rather than faithful replication of surveying instruments. The second dataset is from surveying engineering students who completed leveling labs in immersive and interactive virtual reality using Oculus hardware. The environment and instrument were faithfully modeled in Unity from their physical counterparts, giving a sense of realism. Both game-based and virtual reality approaches have different advantages and disadvantages, that makes them effective in different learning settings. A comparison of these two approaches demonstrates the synergies of future integrated implementation. Lessons learned will help instructors in understanding and identifying the proper technology to address experiential educational challenges that are related with virtually training engineering students.

1. Introduction

1.1 Surveying labs

Introductory surveying courses aim at introducing surveyors / geomaticians and civil engineers into the main surveying principles and data collection methods with modern instruments and techniques. Such courses have considerable outdoor experiential lab components, which give students great hands-on exposure and experience with surveying. However, there are several important challenges such as cancellations due to weather, labs are often conducted in the same location, and students cannot build skills that surveyors need in the field, while the COVID-19 has introduced additional challenges, as many institutions cancelled or reduced outdoor lab

components. Virtual applications can be used to address such challenges and supplement existing teaching methods and experiential labs.

1.2 Background on immersive and Web-based virtual reality

Immersive technologies have experienced widespread application and dissemination in education in the last few years thanks to rapid technological advancements. By immersion in this paper, we mean the spatial immersion that virtual reality implementations with head mounted displays (HMD) enable. Immersive virtual reality leveraging on realistic environments and modeling [e.g., 1-4] has been used in several cases in engineering [2, 5-7]. Virtual reality is often employed in cases where physical experiential learning is not possible. For instance, virtual reality has been used to create training software for marine engineers, where students get experience on working in engine rooms with different emergency scenarios [2]. The authors in [4,7] used virtual reality in civil and geotechnical engineering to train students in rock mapping and identifying virtually rock discontinuities, with their findings indicating that students who used the virtual training tool where better prepared for the physical exercises.

With regards to surveying, virtual reality has been used in the past in desktop-based implementations [8,9]. Despite the benefits, i.e., learning basic principles of surveying, there were few limitations. Desktop-based virtual reality is implemented via a keyboard and mouse, making it difficult to navigate in the environment, impractical interaction with surveying instruments, and difficulty in understanding a complex 3D environment when this is rendered in 2D. The latter is rather important in surveying, as surveyors have to make decisions in the field based on terrain conditions. Recently, surveying educators have started using immersive virtual reality [5-6], which allows for faithful recreations of physical exercises, offers more natural interactions with virtual instruments, and more natural navigation around the environment. However, one of the major drawbacks is the cost associated with such virtual implementations, as users need a higher end gaming computer and virtual reality hardware. The authors in [6] developed a cost-effective mobile virtual implementation, but with the expense of reducing realism and making simplifications. Other virtual implementations in surveying are 360-videos [e.g., 10] that allow users to experience a surveying lab, but without meaningful interactions. Another important implementation are Web-based gamification applications. The digitalization of workflows through interactive Web-based game platforms is becoming a trend these days. This is not only true for the game sector but also for engineering and education. For example, the traditional designer-as-a-user concept was replaced by a Web-based gamification approach to crowdsource the design of virtual environments [11, 12]. Other examples of such attempts are presented at [13-17]. The majority of these studies are all in agreement that gamification and immersive learning environment are an opportunity for experiential education to enhance students learning. The idea of using gamification got a new spin in online learning since the start of the COVID-19 pandemic. Evidence from similar studies suggested gamification approaches as effective alternate for collaborative design, enhancing student's engagement [18].

1.3 Theoretical Basis and Objectives

This paper discusses and compares two different virtual reality implementations of field-based experiential learning applications, namely a game-based Web application and an immersive and interactive one. Pedagogical foundations in virtual reality applications can be categorized as follows [19, 20]: (1) direct instruction, (2) experiential learning, (3) discovery learning, (4) situated cognition, and (5) constructivism. Both virtual tools used experiential learning as the main pedagogical approach. In experiential learning students engage in virtual experiences, observe, think, and learn by doing [21]. A secondary pedagogical element in both tools was discoverer learning [22], where students explore the virtual environment and virtual tools, examine constraints, and engage in problem-solving and decision-making through optimal level challenges. Furthermore, both tools allowed for feedback to students, allowing student to understand what they are doing wrong and correct their mistakes. This adds elements of constructivism as a third pedagogical element [23]. Through feedback, in real time and after the completion of the virtual labs, students can gain knowledge by making sense of their experiences and reflect on their mistakes to improve their surveying practice in the future on the field.

The main objective of this paper is to compare these two different approaches, identify their strengths and weaknesses, as well as their synergies. Each virtual method presents different advantages and disadvantages. For instance, game-based approaches allow for widespread dissemination and less effort in term of hardware/software from students-end, but limit interaction with the virtual environment and instruments through keyboard and mouse. In other hand, immersive virtual applications allow for more natural interactions and navigation; however, the cost associated with computer and virtual reality hardware, prohibits dissemination. Lessons learned will help instructors in understanding in greater depth how these methods can be used to address experiential educational challenges related to virtual training of engineering students with instruments.

The game-based and immersive virtual reality tools are first presented with discussion on their implementations in surveying courses (sections 2 and 3). Next, the two methods are technically and pedagogically compared using qualitative feedback from students (section 4). Finally, the paper summarizes major conclusions and sets remarks for future work (section 5).

2. Description of Virtual Tools

2.1 Description of the immersive tool

The immersive and interactive virtual reality labs were created at Penn State Wilkes-Barre in Unity game engine and they are using Oculus Rift hardware. The lab was based on differential leveling, a procedure that is used in surveying to accurately estimate elevation differences between points [24]. The process requires a differential level instrument and a leveling rod. The surveying instrument, a differential level, was faithfully recreated in virtual reality, replicating its

functions and interactions with students (see Figure 1). A thorough presentation of the virtual reality software, its main components, and technical aspects can be found in [25], while some first pedagogical implementation results can be found in [5]. Students can grab and move the instrument to any location, adjust the length of tripod legs to achieve approximate leveling, adjust the tribrach screws to accurately level the instrument, rotate the telescope of the level to aim towards a leveling rod, change the focus of the instrument and eyepiece, make measurements in virtual reality, and record measurements in a virtual field book. Grabbing and moving objects are implemented very intuitively in Unity, as users can simply extend their arm and grab an object by pressing a trigger on the controllers. However, higher level interaction between the user and the instruments requires fine dexterity, which is difficult to achieve with existing motion tracking. To overcome this, we have employed a virtual tablet approach (see Figure 1), where students can select parts of the instrument (e.g., the tripod leg, tribrach screws, telescope, etc.) and complete the desired task using sliders. Student using this approach can complete virtual labs of differential leveling with mm-level accuracy, much like in the physical world. At the end of each virtual lab, the software generates a PDF report, which for each measurement it captures the state of the instrument (how off-level it was) and the true measurement versus observed ones. This information is then used by the instructor and students to reflect on mistakes made and discuss alternative surveying approaches to improve surveying procedures followed by the students in the future.
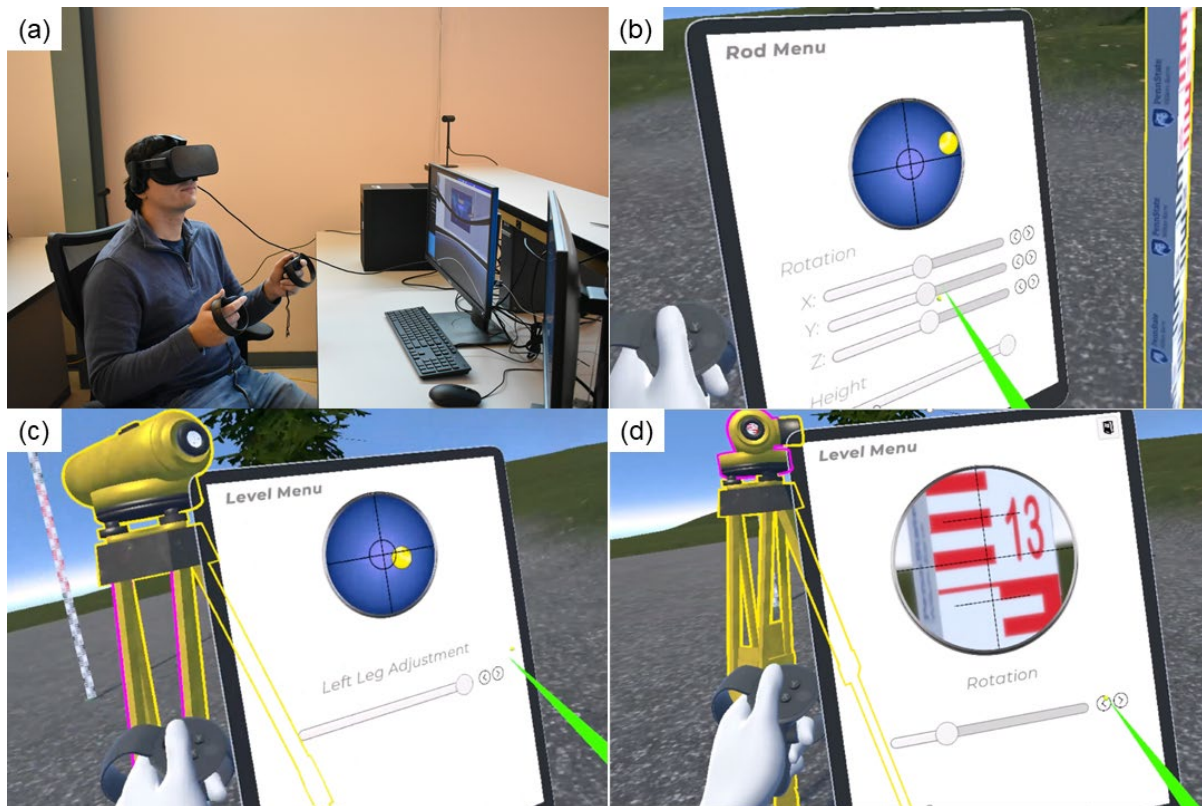

Figure 1. Differential leveling using virtual reality. (a) user in wearing the HMD and managing the controls; (b) leveling the rod; (c) leveling the differential level instrument; (d) making a measurement of the rod.

The virtual environments are based on the campus where students often complete their physical labs [3], but we also offer off-campus virtual environments [25-26]. The virtual labs were designed in such a way that could be completed within 30 minutes in most cases, as users of virtual reality often report nausea and dizziness after excessive use of virtual reality [27-29].

2.2 Description of the Web-based Tool

Under normal conditions, land surveying labs are conducted in-person so that students can gain hands-on experience with the tools and workflows. However, due to the ongoing pandemic, all of the in-person academic activities were suspended. This led us to design a digital platform (as presented in Figure 2) where students can virtually perform land surveying activities (e.g. topographic surveying). We, at York University developed a Web-based gamified experience using the Unity 3D game engine, Unity Real-Time Development Platform [30], for the students to conduct surveying labs. The Web-based labs are based on topographic surveying using a total station [24]. The total station instrument is more complicated than the differential level instrument of the immersive implementation in the previous subsection, and thus more components and functions must be modeled to faithfully replicate this instrument and labs.

The process required creating 3D models of surveying equipment (e.g., tripod, prism pole and total station), as well as the safety kit (e.g., safety helmet and vest as being required by safety regulation in real work experience by Canadian University Protocol for field course). We used Autodesk 3ds Max to create the virtual 3D models of the above-mentioned equipment. We then developed three hypothetical 3D scenes in Unity (indoor building space, an outdoor urban area, and outdoor open spaces), creating instructional step-by-step workflows that students would follow in-person for the labs. After selecting their avatar (Section 1 in Figure 2) and scene of interest (Section 2 in Figure 2), students heading to the safety equipment room first to wear the safety kit (Section 3 in Figure 2), then to the equipment inventory to pick up the required surveying tools (Section 4 in Figure 2), and finally to go out in the virtual field. We wanted to create a realistic experience for students, and therefore, matched the same level of details and steps in our gamified platform as they are involved in real-world surveying. We used the first-person controller as means for students to interact in virtual surveying. Students were allowed to carry out a set of actions (e.g., user-interactivity) in the virtual field, including walking around in the virtual environment, selecting the predefined control points, installing/uninstalling the tripod and total station, adjusting height for the tripod and the prism pole), and taking measurements (e.g., distance and angle between the reference point and target points). To enhance the user experience, we rendered a laser beam from the center of the lens of the total station to the center of the prism pole, and this laser beam would change color (e.g., from green to red) if any object obstructs the line-of-sight between the total station and the target.

Figure 2. A Web-based gamification approach to topographic land surveying.

3. Implementation

The two universities followed different implementations approaches to develop tools based on student needs, specific goals, and restrictions due to the COVID-19 pandemic. The immersive virtual tool at Penn State Wilkes-Barre was used to prepare students for (1) physical labs and (2) train them in different surveying conditions (different terrain complexity and environment). In contrast, the game-based tool was the only option for the program at York University, as physical labs were not permitted due to the pandemic. The implementation followed by each institution are explained in detail below.

3.1 Implementation of the immersive virtual tool

The virtual labs were implemented in the surveying engineering freshman course with seven students, named "plane surveying", in Fall of 2019 at Penn State Wilkes-Barre. A Fall of 2020 implementation could not be conducted due to COVID-19 university restrictions, as students have to share HMDs; thus, indicating some of the practical limitations of such virtual implementations. Plane Surveying is the first course that surveying engineering students take and introducing them to the main principles and data collection methods.

Almost all labs in the course are outdoor experiential labs. Two of those labs are dedicated to differential leveling. Students completed two physical labs on differential leveling and then completed three virtual labs with similar exercises. The virtual labs were conducted in different environment and terrain scenarios to enhance student experience. After the completion of each virtual experience, we asked students to complete anonymous questionaries. These questionaries provided technical and pedagogical feedback. For the purposes of this study, we will be using the students' responses and comments in these questionaries to get insights on the strengths and weaknesses of immersive and interactive virtual reality, and to identify the synergies with game-based Web implementations.

3.2 Implementation of the game-based tool

The virtual Web-based surveying game is designed for the second-year undergraduate course for class size of 65 students named "Land Surveying for Civil Engineers", and was delivered on Late April and early May 2020. It is one of the first courses where students are introduced to surveying principles, tools, and data collection and mapping. The course labs were designed such that the instructor added several control points in the virtual environments. Students were asked to take surveying measurements with reference to the defined control points in the environment stimulating the real field connecting to national survey network. Students are guided to follow the best practice of surveying while performing the game. In order to guide the students to not make mistakes, for example, by installing the total station at a location that is not a control point, we prohibited that action and give the warning (e.g., the installation of the total station at a non-control point) and alerted students with an alarm in the game. Students were asked to take surveying measurements in all three virtual environments and at locations with different altitudes and urban and filed complexity. Students are asked to measure horizontal and vertical angles, slope distance, and instrument and target heights as well as keep track of sketch of measured features. Every measurement could be saved in the game, and in the end, the students were given an option to download their saved measurements as a CSV file for reporting, computation and mapping in AutoCAD and Civil 3D for further labs and assignments. Student could compare their computed coordinates of survey features with the one provided by game system and seek for error analysis and reflect on their quality of surveying.

4. Comparison and Discussion

The comparison of the two virtual tools is organized in three main sub-sections (1) symptoms, (2) technical feedback, (3) pedagogical feedback. Both tools are discussed in each sub-section providing a comparison of their performance, value, and limitations in surveying education.

4.1 Symptoms

The two virtual experiences use different platforms for the implementation. While game-based implementations are Web-based, and students are familiar with working on the browser, the

immersive virtual reality uses an HMD and controllers. Students in the latter case are spatially immersed into the experience; thus, having no situational awareness of the real-world, which is a new experience for most students, and often leads to motion sickness and similar undesirable symptoms. In game-based approach students did not complain about any physical or emotional symptoms, although minor issues of eyestrain and headaches are possible if students spend an excessive amount of time in from of the screen. There was only one student out of 65 who claimed that internet bandwidth issue led to kick off from the game in which the task could not be completed. On the other hand, for immersive reality application using HMD and controllers, in all three labs, five out of seven students indicated that they felt little or a lot nauseous. With two students also indicating the presence of headache and eyestrain. Students indicated that they still enjoyed the virtual reality experience, despite their symptoms; however, the presence of such symptoms introduces limitations. For example, students can become distracted focusing on their symptoms rather focusing on the actual lab, limiting pedagogical outcomes. In addition, due to the presence of symptoms, implementation of such virtual experiences is limited to few times a semester. On the other hand, game-based implementations do not suffer from such symptoms. Thus, there is no need to limit lab duration, as users can spend more than 60 minutes working on the game-based lab without significant symptoms and test their knowledge and skills.

4.2 Technical Feedback

The technical feedback shows that immersive virtual reality can re-produce realistic environments and replicate instruments to high fidelity. Point cloud technologies can be used to create realistic environments, which with the addition of HMD experiences, students feel that they are actual "there", allowing them to immerse in the environment. For instance, some of the comments received indicated that the virtual labs were "extremely immersive" and that "it feels like you are actually there". While most students indicated that the virtual instruments were not hard to use, some students commented that leveling of the differential level instrument was not very smooth and is not very close to reality yet. Replicating complicated instruments in virtual reality can be difficult; therefore, some simplifications had to be made, as the main interaction was done through a virtual tablet [5].

Game-based approach received remarkably positive by students, considering the fact that this was the only solution when the pandemic started. Students felt challenged and assessed for their learning and skills they got from theoretical contents, instructional videos, data analysis and simulation. There is further effort to use Building Information Modeling (BIM) data and 3D Geospatial technologies to create 3D virtual campus model and embed to the game. This will lead to more realistic experience to students working within actual 3D scenes and experience complexity of physical fields.

4.3 Pedagogical Feedback

Both group of students using the game-based and immersive experiences indicated that such virtual experiences were a fun learning method and improved their learning experience in the course.

For the virtual reality tool, the pedagogical feedback showed that, in terms of helping students understand surveying procedures, the immersive virtual labs "followed proper field steps" and helped them understand the fundamentals of surveying. In addition, they stated that it was a "neat" experience and a great hands-on approach. Students also liked the "city" lab experience, which helped them understand the main field constraints when surveying in an urban setting. Furthermore, students complemented the ability to create realistic surveying scenarios that can train students in various conditions such as surveying in the city and in different terrains, which cannot happen in the physical labs. Thus, this provides opportunities for them to exercise problem-solving and decision-making skills. The feedback received from the PDF report from the virtual immersive tool was also very helpful for students to be able to understand and reflect to their mistakes, in order to learn what they should have done differently, gaining practical experiences.

For the game-based labs, similar experiences were observed giving the best hands-on practice to the students in various environments and surveying situations. Students were also asked to list the series of actions need to be taken to perform a topographic survey. Then students engaged with game and tested their knowledge and skills gained from theoretical contents of the course. However, compared to the immersive virtual tool, the game-based tool provides feedback in real time of incorrect decisions and the corrective actions that should be taken. Meaning that if they do not correctly perform any actions while surveying, then the game warns them to repeat the step and correctly perform the required action and does not let them move to the next until the current action is corrected. The action warning system (e.g. "choose right control point", "face target to total station", "red laser for occluded total station signal") at the game-based approach were received very well by students which made them to reflect on their action and follow the best practice. This gives the students the opportunity to see their error or wrongdoing while performing any action right away, which could be very difficult to detect at the field survey until the post-surveying calculations are done.

Issuing student reflections report is out of scope of this paper, however, the pedagogical feedback indicates that students find such virtual applications useful for surveying courses, to prepare them better and ready for physical labs, help them understand main concepts, and give them new experiences that cannot be replicated in the physical environment.

5. Conclusions

Virtual implementations are gaining ground in engineering education, including civil and surveying engineering, to address instructional challenges and limitations with outdoor and in person experiential labs. These labs are crucial for the development of student skills in

surveying; however, such labs are costly, can be cancelled due to weather, and many times are taking place in the same terrain / surveying conditions. The COVID-19 pandemic introduced new challenges, as many such in person labs had to be cancelled, further motivating surveying instructors to explore virtual labs as a solution.

The paper presented and compared two different virtual tools implementations, namely spatially immersed and interactive virtual reality using HMDs and Web-based gamifications. Two different implementations in two different universities were compared. Both implementations were positively received by students, as both allow for training in different instruments, procedure, and conditions; thus, students are able to utilize previous knowledge to exercise problem-solving and decision-making. In addition, both software solutions offer feedback information to students, which in many cases it is unattainable in physical labs. This is important for students to understand and reflect on their mistakes, gaining experience and helping them improve future surveying methods and practices.

However, there are some practical limitations with each method that should be considered. While spatial immersive applications allow for realistic recreation of virtual environments and surveying instruments, they are often associated with higher hardware cost than Web-based approaches. In addition, immersive implementations with HMDs can cause nausea and dizziness to the user limiting their virtual experience, compared to Web-based approaches that have limited to no effects. On the other hand, the immersive experiences allow for more realistic navigation and interaction between the user and the virtual environment and instruments rather the game-based needs heavier development on WebGL to achieve this goal offering immersive experience through Web browser. This can help students consider topographic and environmental constraints in their decision-making, as they are important when deciding optimal instrument setup locations. Therefore, the Web-based approach is desirable in cases where cost and side effects are the issues, while the immersive virtual reality approach can be used in cases where students need to experience surveying practices in higher detail and higher degree of fidelity (e.g., complex terrains and city environments). Hopefully, further development of virtual reality hardware can reduce their cost, making accessible to wider audience. In other hand, enhanced 3D semantic virtual world information in the game-based tool will have promising result.

Future work will focus on further developing the two software to include additional surveying scenarios, functions, instruments, and environments. In addition, we plan in implementing both software to the same group of students, which will allow us to gain additional insights in the synergies between game-based and immersive virtual reality approaches, thus leading to better pedagogical guidelines for implementation within the surveying and engineering context.

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