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Reinforcing Human-Technology Interaction Theory through a Virtual Reality Engineering Training Application

Dr. Jenna Wong, San Francisco State University

Dr. Wong is an Assistant Professor in the School of Engineering at San Francisco State University (SFSU). Her research interests focus on traditional and sustainable structural resilience and engineering education. Her doctorate research at UC Berkeley investigated the applicability of seismic isolation and supplemental viscous damping to nuclear power plants with focus on seismic resilience and safety. After receiving her PhD, Dr. Wong began a post-doctoral fellowship at Lawrence National Laboratory focusing on computational analysis for nonlinear seismic analysis of Department of Energy nuclear facilities and systems. After joining SFSU in 2016, she established an active research lab at SFSU with a diverse group of undergraduate and Master's level students. For her engineering education research, she is interested in exploring how to use technology such as virtual reality and 3D printing to enhance student engagement. She is an active member of ASCE, ASEE, and SEAONC.

Shah Rukh Humayoun, San Francisco State University
Khanh Nguyen
Yongjian Pan

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Abstract

At San Francisco State University, a primarily undergraduate institution and Hispanic serving institute, efforts are underway to explore the efficacy of teaching human-technology interactions through a real application of virtual reality. Virtual reality is an emerging technology in the education field with immense capabilities to transcend beyond time and space boundaries. The Virtual Reality Engineering program at SFSU brings together structural engineering and computer science colleagues to develop a virtual reality platform for engineering professionals and students related to post-hazard structural evaluation training. Supported through a grant by Structural Engineer's Association of Northern California, SFSU is progressively developing an immersive experience for trainees to explore a structure damaged from an earthquake event. Trainees will need to navigate around the structure and control their point-of-view to examine the evidence of damage. Ultimately, the trainees must classify the structure based on acceptable level of occupancy access (i.e. red card - no access, yellow card - limited access, green card - ok for occupancy). This environment is being developed progressively with the first stage of work focusing on a desktop version of this training. Through this project, three computer science graduate research assistants are partaking in all portions of the work which includes the integration of the structural system from Revit to the Unity platform into a 3D model; definition of materials, textures, and light sources; and development of the user navigation system. Student assessment is conducted to evaluate the efficacy of the project approach to see how they were able to successfully apply the concepts of human technology interaction in the engineering application of virtual reality technology. Based on this assessment, future work will endeavor to: 1) perform user studies with civil engineering professionals and students to evaluate the usability of the underlying environment as well as its effects on cognitive load on users' memory, and 2) develop a curriculum to expand the use of virtual reality environments with real engineering applications in computer science courses to teach human technology interaction theory.

1. Introduction

Technical theory can be extremely abstract at the educational level. This leads to extensive reliance on students' engagement with the material outside of the classroom through research and internships to provide real-life context. The use of technology in the classroom is a way to bridge these experience gaps [1-3]. However, there is a question of how to integrate this technology effectively [4-5]. Considering this, a current project at San Francisco State University

(SFSU) is exploring the use of a structural engineering project to explore and reinforce human-technology interaction (HTI) theory.

SFSU is a primarily undergraduate institution (PUI) and Hispanic serving institute (HSI) serving the diverse community of the San Francisco Bay Area. Engineering is one of the fastest growing majors at SFSU; however, in the past few years, only 29% of Hispanic engineering students graduated in six years (average time to Bachelor's degree at SFSU) [6] and only 14% of engineering students secured employment before graduation. Civil Engineering (CE) is an engineering discipline with a broad basis that works on large pieces of infrastructure (e.g. pipelines, buildings, bridges) with few opportunities for hands-on engagement. In SFSU's Computer Science (CS) department, underrepresented minority (URM) students have remained under 36% of the total registered student each time of last five years, while the URM students' graduation rate within two years after achieving junior status is 25% compared to 36% for White and Asian students [6]. A major factor in student success is student engagement [7]. SFSU is exploring the use of virtual reality (VR) technology as an external opportunity to bridge discrepancies in resources.

VR is an affordable technology that immerses users in an artificial interactive environment with visual and auditory stimulation. Research on VR has substantiated its effects on cognitive models, learning behavior, and successful Science, Technology, Engineering, and Mathematics (STEM) application [8-10]. Not surprisingly, VR's presence in education is growing [11-13] and it is time to investigate how it can assist better learning in the classroom [14] and what kinds of learning activities can be done using VR technology in order to increase student personal development and learning [15]. Kinzie et al [16] mentioned that not acquiring the desired knowledge, skills and competencies are the main reasons behind low retention and college completion rates for not only all students but also for racial/ethnic gap in graduation. Therefore, we envision it is the time to explore how a real world understanding through VR would help the students in getting the desired knowledge, skills and competencies; which may help in reducing the racial/ethnic gap within the academic world as well as to increase the graduation rate of all students including URM students.

Human technology interaction (HTI) theory focuses on analyzing how to provide improved and better interaction between the technology and the users [17]. This has various levels of engagement ranging from people's interaction with the underlying technology at individual level to the larger social level, as well as understanding the social and cognitive issues on the interaction users. There is clearly the interaction of the user with the technology. But there is an educational level of HTI and this is the engagement of students with technology [18]. This engagement with technology was previously studied mostly from the perspectives of engaging with technology in its own form or using it as a mechanism for effective educational practices. However, development of HTI for educational purposes opens a new door to explore how it influences students' engagement in applying theory to practice when they are part of such technology development. From this perspective, this study explores how the student team, related to the implementation of computer science theory into practice using a civil engineering application, tackled the challenges faced during the development of the resulting technology for educational purposes.

With such potential, Dr. Wong founded the Virtual Reality Engineering Center (VR Engine) in 2021 with the mission to explore ways of broadening STEM education through VR technology. Through VR Engine's first project geared towards an educational experience for practicing engineers, Dr. Humayoun (Computer Science) and Dr. Wong (Civil Engineering) initiated their collaboration [19, 20]. This work is motivated by the PIs pursuit to explore Next Generation STEM Education using Virtual Reality (NexGSE).

2. Method

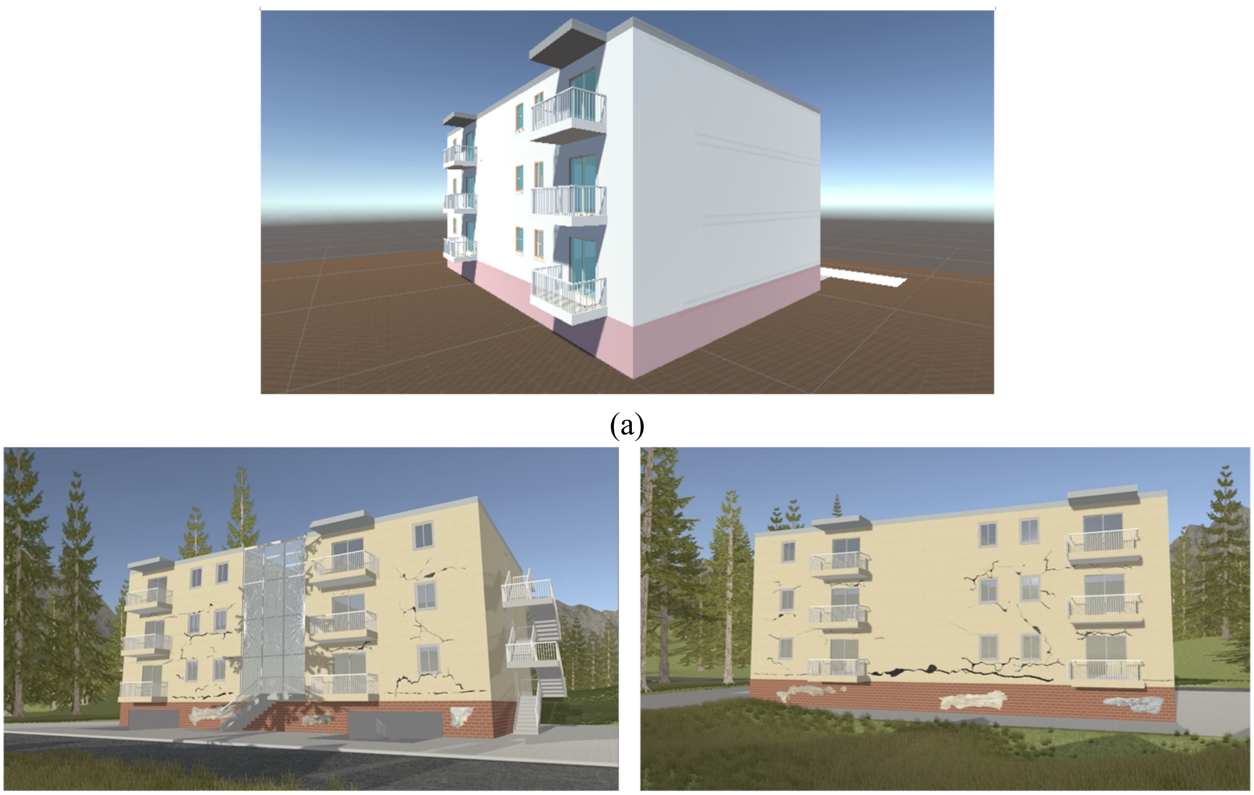
To examine the ability of reinforcing HTI theory thru application, there were various levels of definition needed including the project and participants.

Project - The real-life application utilized for this project was drawn from a collaboration between San Francisco State University and the Structural Engineer's Association of Northern California (SEAONC). SEAONC is a professional organization supporting the structural engineering practicing community with involvement of academic engineers as well. Their organization has several committees including one for Disaster Emergency Services (DES). The DES cooperates with the State of California to provide rosters of trained engineers trained to participate in reconnaissance post-natural hazards (e.g. earthquakes) to evaluate the safety of structures following set criterion. To participate as a rapid-evaluator, engineers must have their professional engineer's license and complete the Safety Assessment Program (SAP) Evaluator training. SEAONC offers this training every 18 months.

The training is conducted through a one-day event consisting of presentations from experts in the field along with case study examples conducted in small groups. These case studies select a structure and present to the trainees a variety of damage scenarios through the use of photographs. Pre-COVID-19 pandemic, these photographs were posted along buildings selected around the training facilities. These mock-ups would require the trainee to walk around the structure but would be deliberately directed to damage points. These photographs of damage may be created via photoshop or stock images from previous earthquakes. Over the past few years, due to the COVID-19 pandemic, this training was modified due to modality. The trainings were conducted online removing the use of physical mock-up structures. Instead, trainees were provided with slides presenting the damage marked on sample structures.

In both versions of the training, there was one major challenge in the curriculum. How to test trainees without deliberately directing them to the damage? In the real-life evaluation, trainees will need to review the building's state independently and determine where the damage is, how significant it is, and how that will factor into their final rating of the structure. This led to the collaboration between San Francisco State University and SEAONC to explore the use of virtual reality to develop a platform to challenge trainees in a new way.

The ultimate goal is to develop a virtual reality case study. The trainee would wear the virtual reality hardware and maneuver their way around the structure. Change of viewpoint and identification of damage would be tasked to the trainee. In the development of this module, the first step is to create a desktop version of this exercise. This allows us to develop the main environment and initiate the elevation of the exercise to include user interactions. This paper covers the development of the desktop training module using the Unity software package. Figure 1 shows 2 views of a building with structural damages in the resulting VR 3D environment.



(a)

(b) (c)

Figure 1: (a) Original undamaged structure in bare environment; Structure's front (b) and back (c) views showing the structural damages in the resulting VR 3D environment.

Participants - To explore the ability of reinforcing HTI and technical computer science material, three graduate student researchers, also co-authors of this paper, were selected to be involved in the project. They were selected based on their experience in computer programming. None of these student researchers had experience of VR application in real-life scenarios.

The students were involved in the project at various levels of the training development. They were provided resources such as the structural system integrated from Revit [21], a building information modeling software. But they were assigned the tasks of integrating the structural system in into the Unity 3D [22] platform; developing appropriate material textures (i.e. brick, masonry), damage asset (i.e. cracking, spalling), integrating environmental features (i.e. lighting, foliage), and navigation processes (i.e. changing user viewpoint and maneuvering around site); and bringing all of these elements together into a working system prototype. The students were provided with mentorship from two faculty members of the San Francisco State University, one from Computer Science department and the other one from Civil/Structural Engineering department), along with feedback from the SEAONC DES committee to advance their work. This support system provided them the necessary technical support while providing expertise in the context of the application.

3. Results

Note: The following reflects the experience of the student participants reported as co-authors to this paper.

Pre-Assessment: Reflecting on the computer science curriculum, the student researchers reflected on their skill sets that were brought together in this project. They initially had confidence levels that ranged from low to average. Subject matters in computer science such as programming in game development, its associated programming language, and how the game development platform (i.e. Unity) integrates with internet hosting service for software development (i.e. Github) were difficult to master prior to starting the project. Additionally, the experience of integrating multiple computer programming languages was an experience they never had which challenged them to better understand the project's structure.

Effectiveness of Reinforcement: One of the impactful components of the project was the fact that game development could be applied in a formal educational training leading to an interactive and engaging experience. The student researchers reinforced skills in programming with C++ with real challenges of creating environments that reflected real physical spaces. This included integrating physic-based theory such as surface penetration. As the trainee or user moved around the structure, the walls could not be penetrated. This reinforced the ideas of boundary conditions and determining how these real physical constraints can be translated to the system. Additionally, they were challenged to implement their knowledge base to 3D modeling as the structural system was a full 3D interactive system. Most importantly, the project emphasized the fact that the field extends far past pure coding. There must be an established understanding of the material and its constraints to create an effective product. This project presented a real physical space that the students were familiar with and could logically connect with.

Challenges: One of the main challenges was getting expertise in 3D modeling application, as none of the student researchers had any prior knowledge of developing 3D modeling and applications. Due to this, it took multiple design iterations before proceeding to the actual development of the underlying 3D VR environment. Furthermore, none of the student researchers had any prior knowledge of working on developing systems for the engineering domain. The lack of domain knowledge was a big challenge in the initial stage. However, with proper training, reading material, and collaboration with team members from the engineering department they were able to cope with this challenge quickly and smoothly. As the project started when the San Francisco State University was still working in remote mode, another main challenge was the collaboration and communication between the team members within the CS background and across the engineering team. A dedicated slack channel and recurring sync-up zoom meeting was helpful to keep all the team members up-to-date as well as to ask for real-time help and troubleshooting. Also, GitHub repository was used to synchronize all the environment development and to keep record of all changes and evolution in the development; however, it took some time in the beginning for the student researchers to get expertise on how things work in the GitHub repository.

Improving Experience: The student researchers proposed multiple suggestions for improving experience of team working for developing such systems. Due to the lack of prior experience in developing 3D environments, it would be great to use wireframing before any development. This would help not only the team members but all other stakeholders to understand and visualize different components of the underlying environment. Furthermore, such a step would also be useful to estimate the time and efforts required for developing the 3D environment as well as to get earlier feedback from other stakeholders. Additionally, having more available resources for students (e.g., special tutorial for developing 3D technology, license to 3D toolkits, availability of 3D hardware, etc.) would be helpful for training new team members as part of such a project.

Overall assessment: The overall impression of the project on the team was positive. The student participants further developed their skills while understanding the extent of a real project's demands. It was especially important to understand and relate the connection to a client team. The feedback and engagement with the client were not continuous but it provided context to the advancement of the project. The student researchers felt their skills were reinforced and enhanced by connecting the theory to a real engineering application. It did challenge their understanding to a subject matter outside of their normal discussions. This provided a level of realistic work that they plan to see in future positions as their technical skills will be applied in various applications.

The tangible understanding of a structural application allowed more logical connection to the project compared to other possible cases. Additionally, they developed a better understanding of their connection with technology as developers. There were various challenges they faced by having to utilize various software to develop a single product. This broadened their perspective of the capacity each software has and the need for integration of technology at various levels. Additionally, as creators, they began to visualize the needs of the users and how they might interact with the product.

4. Conclusions

The learning process is a multi-layered experience. The key component is how you can mesh those layers together. Having separate experiences of learning theory and seeing real-life applications are crucial. But the biggest step in terms of development is the relationship between these experiences and ways they interact.

This project has taken the context of a real-life engineering problem and allowed students to develop the solution and explore it through technology. The interesting part of this project is that the students not only are learning how they are interacting with technology but they are developing technology for users to establish a strong connection with the informative material. The rapid evaluator training context has provided an excellent basis for the student researchers to test and develop their computer science skills within a very tangible application. This was a crucial component that the students could relate to the project even if they did not fully understand every detail of the application. This reflects the process they will experience in industry in working on various projects and tasks that will expand beyond their current knowledge base.

The experience was an overall success due to the collaborative work experience the students had. Having a diverse team with input from the client base for the technical review helped to ensure that the project met its overall goals. Some of the challenges they faced and overcame was the learning curve associated with the application of their technical skills. Having a strong background in theory, they now had to utilize various platforms to produce the product and ensure it was an accurate representation of the engineering needs. This was an eye-opening experience for the team as it showcased the ways in which technology must integrate various software and platforms together. Having the real-life connection to the environment's visuals and the knowledge of how the user will interact with the environment played a huge role in establishing the team's approach.

This is the first product from VR Engine and sets a precedent for future work. Further development is continuing on this same project to elevate it from the desktop experience into the full VR simulation. From here pilot studies will also become part of the identified tasks to ensure that the user base is receptive to the product and inform the teams' work for further advancement.

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