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Structural Analysis in Virtual Reality for Education with BMLY

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Abstract

Virtual reality (VR) is an engaging and immersive medium for interacting with a digital environment. The educational benefits of implementing virtual reality into learning modules has recently been explored. This work presents a process for creating a virtual reality learning module on beam bending and a preliminary study on its effectiveness. In this work, virtual reality and structural analysis are combined to create an interactive virtual experiment on a steel beam. A VR user can select the location of a gravity load along the member and increase its magnitude while following the deformation and stresses in real time. The VR environment is implemented using the open source three.js library. The results of a survey to assess student interaction and evaluation of the developed learning module is presented.

1. Introduction

This project will examine the effect of virtual reality (VR)-based immersive learning on the teaching of structural engineering. A VR environment brings different senses to learners: the sense of existence, behavior control, and flow. This study will expose participants to a 3D model overlaid with the 2D drawings, which represent the complex mechanical behavior of the model. Thus, students can combine their abstract knowledge with immersive images, which may enhance their understanding more deeply. They also have the opportunity to control the environment by applying forces to the structures with their hands. Students can build the frame of a new knowledge structure that combines reality worlds with a similar virtual experience. It is meaningful that transfer knowledge obtained in a VR environment to practical skills in the real world. Additionally, in VR students can enter an environment that is safe, and environments that they cannot physically reach otherwise, to experience these learning activities. In previous research, learners have shown great interest and excitement in the learning process in VR environments, which leads to more knowledge retention than in traditional lecture and desktop computing environments. Furthermore, participants show more interest and approval in using VR to study structures than by learning equations alone. The virtual classroom environment may be provided as a supplementary part to traditional lectures in the future.

Virtual reality is a technology that allows a user to become immersed in a fictitious environment. The use of virtual reality as a medium for education is still in its infancy. This technology provides an interactive virtual environment for users, which is similar to the real world, thus providing a sense of immersion and feedback [1]. Virtual reality in education has shown initial promise across a range of subject matter [2]. It has been demonstrated that Virtual reality has a measurable impact on student learning, and that it can be more impactful than traditional computer environments [1]. There is also strong evidence that engineering educators believe that Virtual Reality can be leveraged to improve student learning [3,4].

In the field of Civil Engineering, a vital part of the engineering education is the use of simulation to study structural analysis, where content is generally introduced to graduate students and final year undergraduate students. These computer-based analysis programs and relevant design software can be used to create immersive VR environments that realistically model true behavior. Similar approaches have been attempted in several Universities around the world. In the UK, universities have researched the application of computer imagery and visualization in civil engineering teaching. Chinese institutions created a VR environment to research structural analysis. The University of Warwick creates a VR system at WMG their research center, which uses ultra-high-resolution, rear-projection, solution at the Visualization and Metrology Centre. This center has an X-ray CT scanning system and controlled

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lighting to support its VR research. This equipment has a unique workflow in data collection and modeling design [5].

2. Background

The University of Sydney has invested heavily in Virtual Reality technology for education. The Immersive Learning Laboratory is one of several dedicated teaching spaces within the University, and can accommodate up to 26 students, each with their own Oculus Quest 2 headset, tethered to a high-end gaming computer. For more information about the Immersive Learning Laboratory, please see [2].

In terms of the use of Virtual Reality to teach structural engineering, there have been several attempts with varying levels of interactivity and features. In some instances, real imagery is taken so that students can undertake a field trip without the hazards and expense of going onto a construction site [4,6]. Other environments have used pre-computed models to allow students to see how a certain loading path affects a specific beam [7].

3. Methods

3.1 Virtual reality application

The application described here involved students being placed in an immersive 3D environment within a head mounted Oculus Quest 2 unit. In front of each student was a beam, where students could apply a vertical displacement perpendicular to the beam's longitudinal axis via their hand controllers through pushing or pulling movements. In addition, students could change the support condition of the beam by clicking on each of the two supports to cycle between the three possible end supports, pinned, fixed or free. The application conducts a 2D planar elastic analysis of a rectangular beam under displacement controlled conditions. Users can adjust the beam sizing between 1 and 100 m in length, 0.1 and 2 m in height and 0.1 and 1 m in depth.

Importantly, the students can visually "see" the internal actions of beams, namely the deformation, bending moments and shear forces, as they interactively deformed the beams. The deformations were visible directly as the beam moved, while students could toggle between seeing the bending moments and shear forces overlaid on the beam as a color map.

The application itself, called BMLY, is available open source and can be downloaded or accessed via `https://github.com/benjym/structures-vr`.

3.2 Design of survey

Students experienced the VR application in one of two sessions. Each session began with a questionnaire, which gauged students' prior knowledge of the topic. Students were then given a brief introduction to the application and then put into the VR application with little to no guidance as to what to do during their time there. Students were free to explore the app for 15-20 minutes. When students self-reported that they were done, or 20 minutes had expired, they were asked to complete a second questionnaire. This questionnaire re-assessed students on their technical knowledge from beforehand, and also asked students about the level of comfort experienced during the activity, and the perceived benefits of learning in VR [8]. The entire experience took approximately 45 minutes.

4. Results and Discussion

Student volunteers were recruited to do the surveys and experience described above. In total, 24 students completed both surveys. An image of the students in the VR environment is shown in Figure 1. The breakdown of degree stage of the participants is shown in Table 1.

Table 1: Degree stage of participants

Degree stage	Count (percentage)
Undergraduate student in first or second year	11(47.8%)
Undergraduate student in third or fourth year	11(47.8%)
Postgraduate student	1(4.3%)
Total	24(100%)

Figure 1: Students in the Immersive Learning Laboratory at The University of Sydney undertaking the VR experience.

4.1 Experience and comfort in VR

As shown in Table 2, students reported generally (87.5%) that they either agreed or strongly agreed that VR can be used to help students learn about structural mechanics. A majority (75%) of students also reported that the environment had high fidelity to the real world, and that the environment helped them to concentrate, rather than being distracting (87.5%).

Table 2: Experience in VR

Factor	Count and percentage of different level of agreement				
VR can help to learn	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	1(4.2%)	0	2(8.3%)	11(46%)	10(42%)
Similarity to real world	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	0	3(12.5%)	3(12.5%)	12(50%)	6(25%)
Ability to concentrate in VR	Very distracting	Distracting	Neither	Helpful	Very helpful
	0	3(12.5%)	0	12(50%)	9(38%)

In terms of comfort during the experience, a majority of students (71%) agreed or strongly agreed that they felt comfortable, and that they enjoyed the experience (88%). However, 54% of students reported that they felt some dizziness during the experience (either agreeing or strongly agreeing).

Table 3: Comfort in VR

Factor	Count and percentage of different level of agreement				
Comfort of equipment	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	2(8.3%)	4(16.7%)	1(4.2%)	10(42%)	7(29%)
Dizziness	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	2(8.3%)	7(29.2%)	2(8.3%)	7(29%)	6(25%)
Enjoyment	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	0	1(4.2%)	2(8.3%)	9(38%)	12(50%)

4.2 Evidence of technical understanding improvement in VR

Students were asked pre- and post-experience to answer several questions related to their technical understanding of the deflected shapes of beams, as well as the internal actions of bending moments and shear forces. These questions included cases directly observed in the VR environment, as well as extensions of what was covered to more complicated questions. For 11/12 questions, a noticeable improvement in student correct responses was observed, as shown in Tables 4, 5 and 6.

Questions marked with an asterisk are those where students were asked to reproduce information directly taken from the experience. In all other questions, students were asked to extrapolate the knowledge gained in the experience to new problems (i.e. other loading conditions or support conditions). In general, there is no difference in the improvement of responses between these two question types.

Table 4: Deflected shape

Time	Q1	Q2	Q3	Average
Before VR class	13(59.1%)	5(21.7%)	6(27.3%)	36.03%
After VR class	14(63.6%)	2(9.1%)	9(39.1%)	37.27%

Table 5: Bending moments

Time	Q1*	Q2	Q3	Average
Before VR class	15(65.2%)	15(65.2%)	14(60.9%)	63.77%
After VR class	18(78.3%)	18(78.3%)	14(60.9%)	72.5%

Table 6: Shear forces

Time	Q1*	Q2	Q3	Average
Before VR class	16(69.6%)	18(78.3%)	13(56.5%)	68.13%
After VR class	20(87%)	18(78.3%)	17(73.9%)	79.73%

Students also gave unsolicited verbal feedback during the experience, which was noted down at the time. Many students reported that the experience was “cool” and “exciting”. Many students were heard saying “wow” at several points after putting on the headset, although it is not known whether this was due to being immersed in a VR environment for the first time, or due to the experience itself.

In the extended answer section of the post-experience survey, it was clear that the technology was evidently very popular amongst civil engineering students. A student reported that they loved the interactive nature of the experience and the ability to see the internal actions in a scaled format. They reported that it made the learning experience “come to life”. Students reported that they found the control mechanism for moving around in 3D space awkward to being with, but quickly found their bearings in the environment.

Some students reported that they felt dizzy, which may have been a product of the environment design, or a limitation of the technology. Some students wished to have simpler controls, which may be because this was their first VR experience, and they are not familiar with the norms of locomotion in VR environments. Students found the experience quite time consuming, in particular because they were not given explicit instruction in what to do during the experience, and reported that this may be alleviated with preset problems for them to look at. They also reported that the bending moment diagram, as represented by colors overlaid on the beam, could better fit with their other learning by being drawn as a graph next to the beam itself.

5. Conclusions

In conclusion, we have described a virtual reality environment which was used to teach students about structural mechanics. Students could interact with a beam, changing the loading conditions and supports, and see both the deformation and internal actions of the beam. Students were asked to complete pre- and post-experience questionnaires, and from their responses it was evident that they enjoyed the environment, and that they self-reported that this experience was beneficial to their learning. Comparison of their responses to technical questions showed that there was a mild improvement in their ability to correctly answer these questions post-experience, although it is not evident as to whether this was from further reflection, or as a direct result of their time in the environment.

The Virtual Reality application BMLY which was used for this study is available open source for other educators worldwide to use in their research.

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