Preliminary Evaluation of Immersive and Collaborative Virtual Labs in a Structural Engineering Unit of Study

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Introduction

In the last three years, the Faculty of Engineering at the University of Sydney has been trialling the use of immersive virtual reality (IVR) in various engineering units of study. The focus of this paper is to present preliminary results of a study that aims to evaluate the effectiveness of immersive virtual reality (IVR) content in supporting student learning of key engineering concepts. Two research assistants independent of the teaching staff used event sampling to observe fourth-year structural engineering students exploring an IVR module during two structured IVR workshops. Inductive content analysis was employed to identify patterns and themes in the data which was collected during observations and to map the relation between observations and student interaction with IVR content. Preliminary results found that the IVR experience varied amongst students in both workshop sessions. The observers also noted limited student-to-student and student-to-teacher communication during the workshops, and inherent hardware and potential software design limitations. Students that verbally communicated with their peers were however generally able to keep pace with each other and complete activities at the same time. These students were more likely to communicate with the teacher in the classroom and less likely to utilise the services of the technical teaching assistants during the session. Furthermore, the practicalities, considerations, and potential improvements to the design of IVR modules and student workshops are discussed.

IVR in Engineering

The use of virtual reality (VR) technology can be traced back to the late 1960s, with Ivan Sutherland's aim to surround users with three-dimensional information via a head mounted display (Sutherland, 1968). Fifty years after Sutherland's experiments, examples of IVR can be seen in various industries. Engineering education is no exception, with IVR presenting the potential for broad and practical applications. A common application relates to safety training through simulated virtual environments, such as training for miners to escape from mine fires and explosions (Ora, Mallet, & Margolis, 2009). Other applications of IVR relate to simulating bench-type physical experiments that help to mitigate high capital costs associated with physical testing and increase student (one time) exposure to experiments. Generally, students' interaction with experiments in classes with a large cohort is very limited (Chaturvedi, Yoon, McKenzie, Katsioloudis, Garcia, & Ren, 2012). IVR within Engineering teaching has also been used to aid student comprehension of complex concepts, such as complex spatial arrangements in structural engineering (Fogarty, McCormick & El-Tawil, 2018). Bower, Lee, and Dalgarno (2016) predict that there will eventually be a merging of real and virtual worlds, so that the two are almost indistinguishable. Until this time, teachers using IVR must consider the pedagogical, technological and logistical factors that can both support and constrain learning with this technology.

Faculty approach to IVR

The implementation and use of IVR within the faculty has broadly been left to the discretion of individual instructors and unit coordinators interested in trialling the technology in their classes. With no top-down directive for faculty staff to implement and use IVR, these early adopters generally wish to either trial the technology or see potential efficacy in the use of IVR in their subjects. The initial investment in time and money in developing IVR content and resources can be relatively high, as compared to developing static content. Questions lie in how to evaluate the effectiveness and appropriateness of investing in IVR. A first step in this process can be an observation of student interaction with IVR content during workshops, presented in this study.

IVR Modules

Structural Engineering IVR Module

We used an IVR module during a Civil Engineering unit of study (UoS) ‘CIVL5277 Structural Rehabilitation and Timber Design’ which is delivered to fourth-year undergraduate and first/second year postgraduate students. The IVR module was designed in alignment with an assignment (Bridge Condition Assessment Project) during which students were required to assess and evaluate one bridge out of six selected bridges based on content that was provided during lectures and workshops. Students were asked to form groups with a maximum of three and minimum of two students per group in order to work on their bridge condition assessment project. For successful completion of the assignment, students were required to investigate various resources, such as engineering standards, guidelines, textbooks, and online materials. Facilitated workshops were designed to scaffold students’ learning of structural assessment and evaluation.

The project included an identification of a selected bridge (due week 2 of semester), the IVR module (delivered in week 3), early-mid design and peer review/feedback (due week 4 of semester), and the final completion of their project (due week 7 of semester). The IVR module was created to introduce students to identifying issues, defects or risks through virtualised three-dimensional (3-D) images of a real bridge (Figure 1). Several 360 images were taken from the bridge using Kandao Obsidian R High Resolution 8K VR Camera. The IVR content was produced using an A-Frame web-based platform.

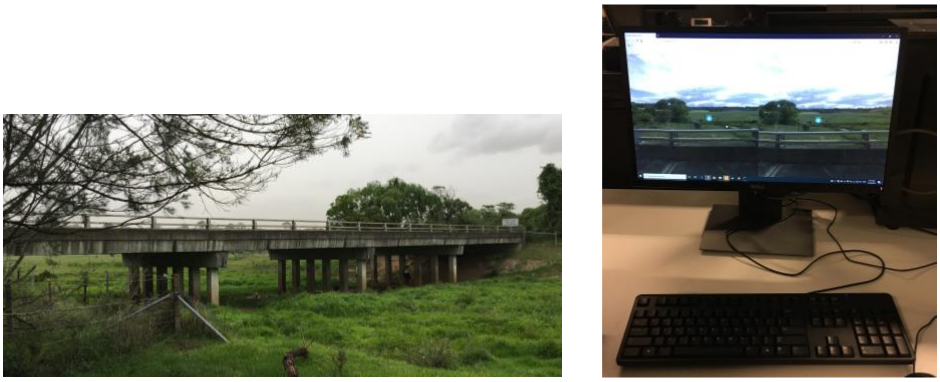

Figure 1: Investigated bridge and 2D representation of IVR content on the monitor.

The IVR module aimed to help students visualise the assessment and evaluation of an in-service reinforced concrete bridge and to facilitate their experiences in new unique situations. An initial benefit and impetus for the creation of this IVR module involved mitigating potential student exposure to safety hazards and risks which could arise from conducting physical site visits, while still providing an immersive experience to students of bridge condition assessment. The IVR module also had additional benefits as physical site visits can also be limited due to logistical costs, limited (one time) exposure to the site, limited students’ interaction with the site due to temporal factors, and limited teacher site guidance and support due to potentially large student group sizes.

Evaluation Methodology

Event sampling by two research assistants independent of the teaching staff was conducted across two one-hour IVR workshop modules. The event sampling approach aimed to record all occurrences of targeted behaviours and events during the workshop. Targeted behaviours included instances of interpersonal, physical and virtual student behaviour. Examples of interpersonal behaviour involved student-to-student, student-to-teacher, and student-to-technical teaching assistant interactions. Examples of physical behaviour involved recording physical activities, such as students removing their IVR headsets and looking around the workshop room. Examples of virtual behaviour included recording what participants were doing in the virtual environment, such as their virtual location and the activity they were completing at the time. Examples of events included students entering and leaving the workshop and the facilitator providing instructions at the commencement of each activity. The research assistants completed subsequent inductive content analysis of the event sampling records to identify potential patterns and themes in the data, and potential theories that could explain these.

The IVR laboratory room layout is shown in Figure 2a and b. Student stations are set up in 8 banks of 3 workstations with instructor and overflow workstations available on the far left. The instructor generally stands towards the 'front' or lower portion of the diagram.

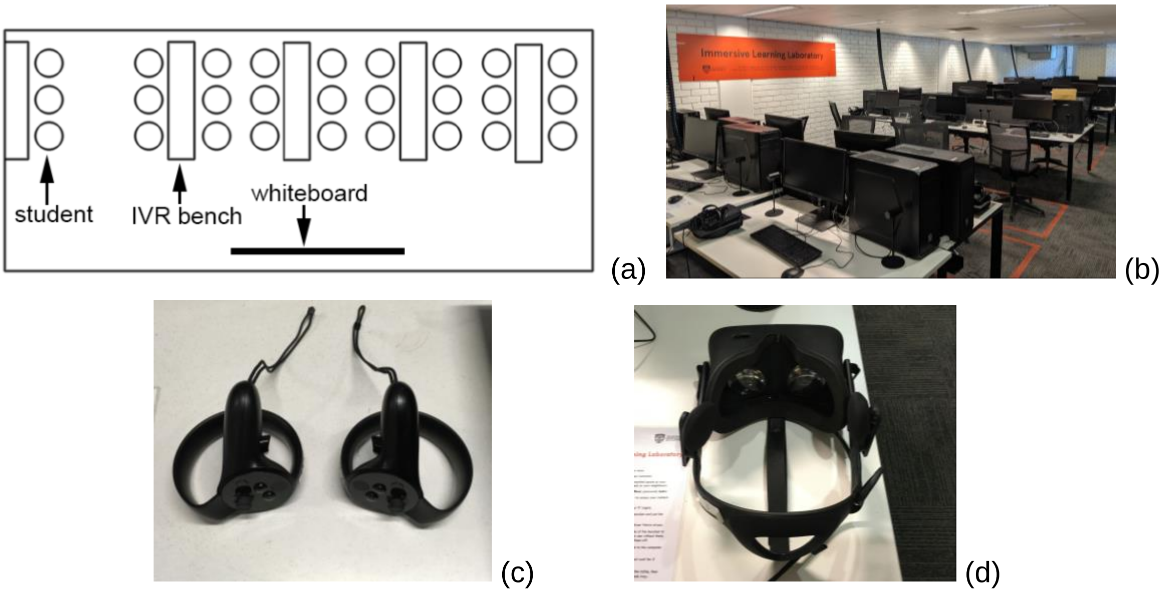

Figure 2: (a and b) The IVR laboratory room layout, (c) touch controllers, and (d) VR headset.

There were 46 students in the unit and based on capacity of laboratory, they were divided into two groups to attend the IVR session. The workshop consisted of 19 students in the first group and 20 students in the second group. The design of the IVR workshop was structured around six key activities (see Table 1), with observations occurring across the whole workshop. Prior to the IVR workshop students were assigned to teams of three and were instructed to sit with their team members upon entering the workshop. The general structure of the workshop involved participants being provided instructions of the task and set up of their IVR equipment (Activity 1). The IVR equipment included an oculus rift touch controller and a headset (Figure 2 c and d). Student were sited on chairs during the whole IVR experience and were able to move their hands and head around to walkthrough the bridge. It is worthwhile to mention that while students were using VR headsets, instructors could see what students were observing on the monitor (Figure 1b). The IVR bridge assessment started with students reading a completed risk assessment form within IVR environment (Activity 2). Participants were then free to explore the IVR module, while applying prior knowledge and skills to conduct an assessment of the virtual bridge (Activity 3). Participants then took a short quiz to check their understanding of various bridge defects – this quiz was undertaken inside the IVR content, with students using the hand controller to select multiple choice answers with marked answers shown immediately following the quiz (Activity 4). During Activity 5, participants re-explored the bridge, but this time additional information was provided on IVR content in the form of annotations to scaffold students' learning of structural assessment and evaluation methods. Annotations highlighted potential causes for each defect and suitable destructive or non-destructive techniques for evaluation of defects. The IVR workshop ended with a small group and facilitated discussion of participant experiences (Activity 6). The IVR session was completed in one hour.

Verbal instructions were provided by the teacher in the session for students to move from activity to activity. There were also one teaching assistant and one technical assistant present to assist students experiencing technical or conceptual difficulty during the workshop.

Table 1: Structural Engineering IVR Observation Stages

Activity	Stage Detail	Observation Protocol
1. Pre task Instruction & IVR set-up	Teacher instruction of the task and participant physical set-up of IVR equipment.	Observe participant verbal and non-verbal listening skills and general attitude towards the task. How do participants react to instructions, e.g. can they set up their IVR environment effectively and efficiently? Do they appear enthusiastic about the upcoming task? Do they require technical teaching assistant help with this stage? How long do they take to reach the 2nd stage?
2. Risk Assessment	Participants view risk assessment written content within the IVR.	Observe whether participants engage with the risk assessment content deeply or choose to simply explore the IVR environment. How engaged are participants with the risk assessment content? Do they seek teacher clarification with this task?
3. Walkthrough without annotations	Participants complete an unstructured task where they are asked to look at and walk around a bridge to observe any issues, defects or risks with the bridge.	Observe whether participants can navigate effectively within the IVR environment e.g. can they navigate from the top to the bottom of the bridge? Do they appear lost? What are students focusing on and is this risk or issue related?
4. Quiz	Participants are provided with an IVR quiz on potential risks/issues that they may or may not have observed. Self-written quiz mark totals also handed in.	Observe participant reaction to their individual results. Do they freely accept their results, do they challenge them, discuss them with their peers, do they re-examine the bridge elements?
5. Walkthrough with annotations	Participants complete a semi-structured task where they walk through the same bridge environment, with IVR annotations indicating structural and non-structural defects on the bridge, possible causes, as well as	Observe how much time participants spend on each annotation and whether participants are engaging with the annotations.

	assessment and evaluation methods based on Bridge Standards.	
6. Class debrief	Participants are asked to take off their headsets and discuss in groups whether the session improved their learning and how it may help them to complete their Bridge Condition Assessment Project.	Observe participant feedback of the activity, whether they felt this was a positive experience or not.

Results and Analysis

Inductive content analysis of the event sampling records across each of the six IVR workshop activities was examined. The findings are outlined as follows.

Observers noted in both sessions that even though there was a structure to IVR workshop activities, the pace that each student worked through each of the activities differed. This was particularly true for groups with minimal or no verbal communication amongst team members. This could be attributed to several factors. Some students arrived late, while other students took longer than others to orientate themselves to the IVR equipment. Some students experienced technical difficulty requiring logging in and out of the system. Other students, when they appeared 'virtually' lost, or had difficulty moving from activity to activity, also logged out and back into the system. Overall the IVR experience differed amongst participants. This was particularly the case for students that required more technical teaching assistant help throughout the session. These students naturally did not have the time to delve as deeply into the activities as the students who didn't require as much assistance.

The observers noted that in both sessions students were generally quiet, with the second session quieter than the first session. The students also generally treated the IVR workshop as an individual activity. In the first session there was one row of three students that talked throughout the session about the content related to the workshop with their headsets on. This group was potentially a catalyst for triggering students in their immediate vicinity to talk, and this 'seed group' helped normalise talking amongst themselves with headsets.

Students that verbally communicated together were also able to keep pace with each other, completing activities generally at the same time. These students were noted by the teacher to be highly motivated and engaged students more generally throughout the unit, which would likely explain their more efficient performance in this activity. Two of these three students were known to the teacher prior to the start of the course. They were working under supervision of the teacher on their final year thesis project. The specific behaviours they exhibited were sharing technical insights into using the equipment, thoughts on what they were viewing in each activity, their location in the activity, and feelings about their experiences during the activities. These students were also more likely to communicate with the teacher in the classroom and less likely to utilise the services of the technical teaching assistants.

11:25 – All 3 students in risk assessment activity

Student 7 - Hey I can see your laser (pointer). Mine's frozen.

Student 8 - How do you go down to the next page?

Student 9 - You just click it with your right trigger.

Student to student verbal communication was however noted as one-directional in several instances. This could potentially be attributed to the IVR headsets limiting non-verbal communication, or distracting students from more in-depth analysis and collaboration with each other.

11:28 – All 3 students in walkthrough without annotations activity

Student 7 - (calls teacher over) Pretty good (bridge) condition, right?

Student 8 - Now I can see your laser pointing at me.

Student 9 - Yours or mine? Ok I'm back on top of the bridge.

11:39 - All 3 students viewing annotations

Student 7 - It looks like it's corroded underneath.

Student 8 - quietly viewing annotations.

Student 9 - These goggles are so annoying.

When students were wearing their headsets, their sense of sight was limited to what they were seeing through their headset. This limited activities, such as visually tracking where the teacher was in the room. It also limited student monitoring of what they were doing in relation to other students around them. The observers noted at several points some students taking off their headsets to watch their peers to possibly see where they should be up to, or possibly to confirm what they were doing was correct. As with face-to-face workshops, the observers noted similar student distractions, such as students taking off their headsets to view their mobile phones and chatting about non-IVR workshop related things.

Interestingly the students e.g. in the above quotes made inferences about the IVR system that were not correct. The system was not networked and what occurred in one machine had no influence on any other, yet several instances occurred of students 'seeing' activity from their group members within this environment, such as the pointing laser in the above quote. This led to students trying to 'find' one another in the environment (a fruitless exercise) – actions strongly related to ideas of identity and presence in virtual worlds as discussed by Lombard & Ditton (2006).

When all students took off their headsets, they saw this as an opportunity to talk to their peers, though the majority remained quiet with their headsets on. Interestingly, in both sessions the more 'chatty' students sat in the same location, towards the middle of the room. Unlike the first session, in the second session when students took off their headsets there was minimal talking. This could potentially be attributed to the second session students attending the IVR workshop directly after a tutorial and experiencing possible fatigue from this.

During all the activities in both sessions, the teaching assistant and technical assistant were kept busy assisting students. Students requiring help would often take off their headsets to call the assistants over. Some students required assistance but either did not realise this or did not want to ask for help, with assistants noticing issues on the desktop monitors and approaching the students unrequested. The issues experienced by students were either user or technical related. One unique issue was one student being unable to use the IVR headset as it would not fit over his head. This student worked around this limitation by operating the headset by hand and viewing their monitor.

The depth and quality of learning for students that required higher levels of assistance throughout both sessions would vary, simply due to the time taken for the technical teaching assistants to attend to each individual issue. This is not simply a case of more assistance necessarily being worse. The teaching assistants, while often performing technical assistance rather than conceptual assistance, frequently took time to explain concepts and underlying theory as well as answering their technical questions. In this way those students who struggled with the system itself ended up having a disproportionate amount of direct instruction and feedback.

Discussion and Conclusion

This study has highlighted the potential efficacy and importance for teachers to design workshop strategies that explicitly promote student-to-student communication and collaboration during IVR workshops. Students that verbally communicated with their peers during the workshop were generally able to keep pace with each other, complete activities at the same time, and were more likely to communicate with the teacher in the classroom and less likely to utilise the services of the technical teaching assistants. Designing IVR workshop activities that actively promote student-to-student collaboration may help to increase student communication, mitigate reliance on technical teaching assistants, and ultimately increase student experience with the workshop.

The IVR headset hardware did appear to limit certain activities and behaviours normally found in traditional non-IVR workshops. While wearing the headset, one potential limitation of the hardware was the elimination of eye contact between students and between students and the teacher in the workshop. Students being unable to see their peers during the module may have implicitly promoted the IVR workshop as an individual activity. Being unable to visually track the location of the teacher in the room while wearing the headsets may have also eliminated key non-verbal workshop communication. Designing designated times during the workshop for students to physically take off their headsets and interact and communicate with peers and the teacher may help to mitigate the ‘real world’ visually limiting nature of the IVR hardware.

The study highlighted several instances where the IRV workshop module software could also potentially be improved. Students who required more technical teaching assistance support did not have time to delve as deeply into the workshop activities as the students who didn’t require as much assistance, limiting their experience of the workshop. When students experienced technical difficulty in the IVR module or appeared lost in the virtual environment they would also often log out and restart the module, a time consuming process. Another observation related to student inferences about the IVR system that were not correct, such as students trying to find each other in the virtual environment. Usability testing to inform future refinement of the design of the IVR module software may mitigate student reliance on technical teaching assistants and further help to orientate and support students in the module.

The IVR module was designed to mitigate potential student exposure to safety hazards and risks which could arise from conducting physical site visits. This study has highlighted that the provision of an immersive experience to support student learning of key engineering concepts is possible. A continuous improvement focus on the design and delivery of both IVR modules and workshops will further help improve student experience in this environment.

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