Enhancing Mining Education through the use of a Scenario-based Virtual Reality Simulation

Jovan Richard Harrod

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ABSTRACT

Virtual reality (VR) has been identified as a means of bridging the gap between theory taught at university and its practical applications in industry. Recent technological advancements in the gaming industry has allowed for the development of low-cost, high performance VR systems. Mining education stands to benefit significantly from these advancements.

This thesis focuses on the development of a large-screen, semi-immersive VR simulation which monitors a potential slope failure at an open cut coal mine over the period of a week and its use in a paired-data observational study. The simulation was designed to compress a week of monitoring into a one and a half hour simulation. The observational study was conducted in the UQ course "Mine Management" with fourth year undergraduate mining students. Students, in groups of four, were given a week to complete a written assignment which provided them with relevant information for a hypothetical open cut coal mine, at which a potential slope failure was being monitored. Students were asked to develop a Trigger Action Response Plan (TARP) to manage the potential slope failure using monitoring triggers with appropriate trigger levels. After they had submitted their TARP they were taken through a one and a half hour VR session with the developed simulation which allowed them to explore the virtual mine site and monitor the slope displacement and rate of movement which was provided through an in-game slope monitoring system. This slope monitoring system updated every hour according to the defined timescale. Students were then asked to re-develop or edit their TARP in the VR session and submit it for assessment. The results of the two TARPs provided two data sets which could be analysed using a paired t-test.

The results of the paired t-test for the nineteen groups that completed the assessment determined that an absolute difference of 19% in the mean assessment result was observed between the written and VR assignment results. The relative increase in the results from written to VR was calculated to be 32%. As the P-value for the paired t-test was found to be 0.000 (<0.05), the mean difference and relative increase can be considered statistically significant and provide strong evidence for the benefits of using a VR simulation to enhance mining education.

<u>Declaration by author</u>

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Publications during candidature

Harrod, J R, Knights, P and Kizil, M, 2015. Enhancing mining education through the use of virtual reality learning and assessment tools, *Proceedings of Virtual Reality (VR) and spatial information applications in the mining industry Conference 2015*, Pretoria, South Africa, pp 31 – 42 (South African Institute of Mining and Metallurgy).

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Contributor	Statement of contribution
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	Contributed to study design (70%)
Peter Knights	Edited paper (15%)
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Mehmet Kizil	Edited paper (15%)

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AEB: Advanced Engineering Building

API: Application Programming Interface

CPU: Central Processing Unit

CSHS: Corinda State High School

DK2: Oculus Development Kit 2

DSFRM: Dynamic Slope Failure Risk Management

FOV: Field of View

HD: High Definition

HDR: High Dynamic Range

HMD: Head-mounted Display

HUD: Heads-up Display

ILF: Immersive Learning Facility commonly known as the UQ VR lab

LED: Light-emitting Diode

OSG: Open Scene Graph

PBR: Physically-based Rendering

RAM: Random Access Memory

RoM: Rate of Movement

SDK: Software Development Kit

SMS: Slope Monitoring System

TARP: Trigger Action Response Plan

UI: User interface

UNSW: University of New South Wales

UQ: University of Queensland

VE: Virtual Environment

VR: Virtual Reality

1. INTRODUCTION

Mining is a technology driven industry that is constantly trialling and implementing new technology to improve safety and production. Graduate mining engineers entering the industry are required to have a detailed understanding of the workings of a mine site. This detailed understanding of the intricate details of the mining process and all other mining related concepts is developed over the duration of their undergraduate degree and is influenced by numerous factors which affect 'how' and 'what' they learn.

In order for students to see the practical applications of the theory taught at university, they need to visit a mine site. However, this is not always practical or possible. The use of Virtual Reality (VR) in mining education has been identified as a means of bridging the gap between theoretical knowledge and its practical applications. Kizil (2003) stated that the difference between conventional and VR training is that VR immerses trainees in realistic and functional simulations of real workplaces and equipment. The famous quote from Confucius: 'Tell me and I'll forget; Show me and I may remember; Involve me and I will understand,' provides a simple yet effective rationalisation for the use of VR in education.

Kizil, Kerridge and Hancock (2004) stated that VR simulations would become more widespread in education and training in the mining industry in the coming years as the hardware required to run VR simulations becomes more affordable and readily available. That was more than ten years ago and today the average desktop computer, laptop or smartphone is capable of rendering 3D objects and animations with ease. Technological advancements in VR for gaming have allowed for the development of low cost, high quality VR hardware targeted at gamers who want to enhance their gaming experience through full immersion. Mining education stands to benefit significantly from these technological advances as it allows for focus to be placed on VR content rather than the hardware of the system and how it works.

1.1   RESEARCH QUESTION

The research question addressed in this project is:

- What effect does using a VR simulation to present an assignment in mining education have on student results when compared to the traditional methods for scenario-based learning objectives?

This research question was addressed by a paired-data observational study conducted with 4th year mining students. The results from which were analysed and used to determine the effect (positive or negative), and quantify the benefits of using VR simulations in scenario-based assignments with undergraduate students in mining education.

1.2   SCOPE

This research project focussed primarily on the use of VR-aided learning in mining education at a university level. While the simulation developed in this project may have commercial significance, commercial applications of VR in mining and commercial mine training simulators were outside the scope of this study and were therefore not investigated. Details of the programming and modelling of the simulation is not discussed in-depth in this report however, an overview of the software packages used and their description is provided.

1.3   AIMS AND OBJECTIVES

The aim of this project was to determine the increase in student assessment results when presented with a scenario-based assignment using a VR simulation as opposed to the traditional written format and thereby provide a simple quantification of the benefit of using VR in mining education.

The primary objectives of this research project were:

- To develop a VR mining simulation using the five roles of a student in a constructivist learning environment as a framework;
- To conduct a paired-data observational study using the developed simulation with 4th year mining undergraduate students; and

- To use the results from the paired-data observational study to provide a quantification of the benefits of using a VR simulation as the medium of presentation for scenario-based assignments in mining education.

2. VIRTUAL REALITY AND EDUCATION

2.1 WHAT IS VIRTUAL REALITY?

Various literature sources provide different definitions of Virtual Reality (VR). Stothard *et al* (2008) define Virtual Reality as *"a technology that allows a user to interact with a purely computer-simulated environment."* They go on to describe virtual reality environments as primarily visual experiences that can be similar to the real world, such as simulated aircraft pilot or combat training, or it could be expressively different from reality, e.g. computer games.

Virtual reality systems can be divided into two major components:
1. Hardware; and
2. Software.

The following sections provide information about the two major components of VR systems and examples of the equipment used to create these systems. This is provided as part of the research that was conducted to understand VR systems and how they operate in order to better understand how the systems are implemented and their use cases.

2.1.1 VR Hardware

The hardware used in VR simulations encompasses a broad range of displays, input and some feedback devices. Hardware selection is based on the end user requirements and the level of immersion that needs to be achieved.

2.1.1.1 Display Systems

Stothard *et al* (2008) provide a taxonomy of VR systems which classifies VR systems by display type which in turn relates to the level of immersion (non-immersive, semi-immersive and fully immersive) experienced by the user. Table 1 shows the classification of display systems provided by Stothard *et al* (2008, adapted from Milgram and Kishino, 1994).

TABLE 1.

Classification of mixed reality display systems (Stothard *et al*, 2013)

	Description	View window on world (WOW)	Large screen displays	Stereo capable	Real world content optical or video	Immersive – full, semi, non	Opaque/ transparent	Video reality added to computer generated image	Individual or group use
Class 1	Monitor based video displays with capability to show video and computer generated graphics simultaneously.	Yes	No	Yes	Video	Non	Opaque	No	Individual
Class 2	Head-mounted video displays with capability to show video and computer generated graphics simultaneously.	No	No	Yes	Video	Full	Opaque	No	Individual
Class 3	Head-mounted video displays with capability to see through to real world and show computer generated graphics simultaneously.	No	No	Yes	Optical	Full	Transparent	No	Individual
Class 4	Head-mounted displays with capability to show video of real world and computer generated graphics simultaneously.	No	No	Yes	Video	Full	Opaque	Yes	Individual
Class 5	Large screen(s), completely graphic display environments with capability to show computer generated graphics and video simultaneously.	No	Yes	Yes	Video	Full and semi	Opaque	Yes	Individual or group
Class 6	Large screen(s), completely graphic environments that are partially immersive and use real physical objects or haptic devices to play a role in the computer generated scene.	No	Yes	Yes	Video	Semi	Opaque	Yes	Individual or group
Class 7	Large full surround screen(s), completely graphic environments that are fully immersive and use real physical objects or haptic devices to play a role in the computer generated scene.	No	Yes	Yes	Video	Full	Opaque	Yes	Individual or group
Class 8	Device with capability to see through to real world and show computer generated graphics simultaneously.	Yes	No	Yes	Optical	Non	Transparent	No	Individual or very small group 1 - 3
Class 9	Hand-held mobile device with capability to show video of real world and computer generated graphics simultaneously.	Yes	No	Yes	Video	Non	Opaque	Yes	Individual or very small group 1 - 3
Class 10	True holographic devices.	No	No	Yes	Optical	Semi	Transparent	No	Individual or group

This project focussed on Class 2 and 5 systems. The Class 2 system being the Oculus Development Kit 2 (DK2) and the Class 5 system being the semi-immersive, 180 degree curved-screen in the Immersive Learning Facility (ILF). A detailed description of the display system in the ILF is provided in Section 2.4.3. The use of these two systems allows a comparison of an individual VR experience (Class 2) with a group experience (Class 5).

- Oculus Development Kit 2

The Oculus Development Kit 2 (DK2) (shown in Figure 1) is a head-mounted display (HMD) for VR that provides a fully immersive experience for the user. Table 2 provides detailed specifications of the DK2.

Figure 1. Oculus DK2 unpacked. (Rudderham, 2014)

This lightweight HMD is one of the most immersive VR experience currently available (as at November 2015) to developers (Oculus VR, 2015). It features a HD resolution display which is divided in half and special lenses to produce an image for each eye thereby creating a side-by-side stereoscopic 3D image. It uses internal and positional

tracking to allow the user to not only look around the virtual environment in 360 degrees but lean in to get a closer look at objects in the simulation.

TABLE 2.

Oculus DK2 Technical Specifications (Oculus VR, 2015)

Display	
Resolution	960 x 1080 per eye
Refresh Rate	75 Hz, 72 Hz, 60 Hz
Persistence	2 ms, 3 ms, full
Viewing Optics	
Viewing Optics	100° Field of View (nominal)
Interfaces	
Cable	10' (detachable)
HDMI	HDMI 1.4b
USB Device	USB 2.0
USB Host	USB 2.0 (requires DC Power Adapter)
Positional Tracker USB	USB 2.0
Internal Tracking	
Sensors	Gyroscope, Accelerometer, Magnetometer
Update Rate	1000 Hz
Positional Tracking	
Sensors	Near Infrared CMOS Sensor
Update Rate	60 Hz
Weight	
Weight	0.97 lbs (without cable)
Included Accessories	
Included Accessories	HDMI to DVI Adapter DC Power Adapter International Power Plugs Nearsighted lens cups Lens cleaning cloth

2.1.1.2 VR Input Devices

The interaction component of any VR simulation is integral to creating a fully immersive learning environment. Input devices are used to facilitate this. In order to determine which input device would be suitable for use in this project, a number of input devices were researched. The list of input devices shown in Table 3 includes examples of low latency, high performance VR interface systems currently commercially available or to

be released in 2015 which are compatible with Windows and come with software development kits (SDK's).

TABLE 3.
VR Input Devices 2014

Input Device	*Description*	*Price*
Project Perception Neuron	Motion tracking/capture system	$1,000 + postage (Dual 30 Neuron Package)
STEM System	Wireless motion tracking system	$580 + postage (5-Tracker STEM System Bundle)
PrioVR	Motion tracking system using high performance inertial sensors	$430 + postage (17 sensor suit Pro)

8 sensor suit
Lite

12 sensor suit
Core

17 sensor suit
Pro
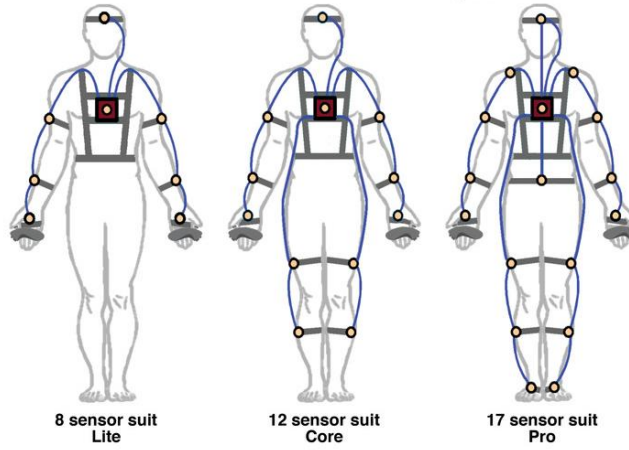
| Leap Motion for VR | Motion tracking using infrared for Oculus Rift DK2 or independently | $45 + postage (Includes VR developer mount for DK2) |

| Virtuix Omni Natural Motion Interface | Natural motion interface (Allows user to walk/ run in 360 degree virtual environment when used with Oculus Rift/ other VR system) | $500 + postage |

Microsoft Kinect 360	Infrared motion sensor using structured IR	$200 + postage

- Leap Motion

The Leap Motion Controller is a gestural control interface for PC and Mac which tracks hand and finger movements using two cameras, three infrared LEDs and advanced algorithms (Leap Motion, 2014). When combined with the Oculus DK2 it acts as an input device which allows the user to see and use their hands in VR. The controller has a 135 degree Field of View (FOV) which is greater than the FOV of the Oculus DK2 (which is 100 degrees) as shown in Figure 2. This allows the controller to track the user's hands before they come into their FOV when used with DK2.

Figure 2. Leap Motion + DK2 FOV interaction (Leap Motion, 2014)

The Leap Motion controller is also used in an up-facing orientation to allow for desktop interaction and was used in this project to facilitate hand interaction with the simulation.

2.1.2   VR Software

VR simulations being developed for educational purposes need to be high resolution and visually stimulating so as to immerse the viewer in the Virtual Environment (VE) and hold their attention for the duration of the simulation. While Autodesk 3DS Max is the industry standard in 3D modelling and rendering software (Autodesk, 2014), there are numerous game and simulation engines used in the simulation development and game development industry that are capable of producing high quality simulations. Stothard and van den Hengel (2010) provide a review of game engines in their paper detailing the development of a Serious Computer Game (SCG) based training module. The review places engines into three categories:

- Open Source;
- Commercial; and
- AAA (means commercially accessible, high license cost, high quality with large user community (Stothard and van den Hengel, 2010)). An adapted version of their review is presented in Table 4.

The major difference between commercial and AAA engines are, for AAA engines the license cost is much higher, the standard of user and technical support is higher and there is a large online community for development support.

TABLE 4.
Game engine review (adapted from Stothard and van den Hengel, 2010)

Engine category	Engine name	Comments
COMMERCIAL ENGINES	Virtools	Comprehensive visual scripting language based authoring package (UNSW development team had over 3 years experience using this package at an exceptionally high level.)
	Quest 3D	Visual scripting language based authoring package, with similar features to Virtools
	Torque	Ageing game engine with distributed networking capabilities
	C4 Engine	Inexpensive games engine with good licensing agreement. Supports COLLADA

	Virtual Battlespace 2*	Military based simulation engine currently used by the Australian Defence Force. Increasing in popularity among the serious games community
AAA ENGINES	Unreal Engine 4 (UE4)*	Epic's major award winning game engine. Used both by Epic and a large number of third party developers.
	CryEngine (4th generation)*	CryTek's next-gen engine used in Crysis. High system requirements, but generally recognised as a leader in real time rendering research and technology. Growing popularity amongst academic/serious games community
	Unity 5*	Unity is a game development ecosystem: a powerful rendering engine fully integrated with a complete set of intuitive tools and rapid workflows to create interactive 3D and 2D content; easy multiplatform publishing (Unity, 2014)
	Source Engine	Valve's game engine used for Half Life 2 series. Ageing, but still popular.
	ID Tech 4	Pioneering game engine of its time used for Doom3
OPEN SOURCE ENGINES	Panda 3D	Carnegie Mellon University's free Python based engine. Used by Disney for a variety of projects
	OGRE	Object oriented Graphics Rendering Engine. Available in several programming language bindings
	Nebula 2	Radon Labs' game framework. Used by several European commercial games
	Crystal Space	Popular object oriented game engine
	Irrlicht Engine	Game engine supporting COLLADA format
	OpenSceneGraph (OSG)	The OpenSceneGraph is an open source high performance 3D graphics toolkit, used by application developers in fields such as visual simulation, games, virtual reality, scientific visualization and modelling. Written entirely in Standard C++ and OpenGL it runs on all Windows platforms, OSX, GNU/Linux, IRIX, Solaris, HP-Ux, AIX and FreeBSD operating systems (openscenegraph.org, 2014).

The information in Table 4 in conjunction with further online research was used to determine the most appropriate engine to use for this project.

2.1.3 Dimensions Affecting Realism

Stothard *et al* (2008) identified two dimensions affecting realism in VR displays proposed by Milgram and Kishino (1994). These two dimensions were image quality and immersion.

2.1.3.1 Image quality

The quality of the simulation from a visual perspective plays a large role in the level of realism experienced by the user in VR. Therefore the 'look' and 'feel' of the simulation needs to be as close to reality as possible so as to suspend disbelief and allow the user react to the VE as they would in reality. Stothard *et al* (2008) state that in the case of mine training simulators for group based training, the image resolution plays a major role, particularly where subtle details need to be demonstrated. For example, in the case of gas outbursts in underground mines, the geological indicators are so subtle that only a trained and experienced geologist would recognise them easily. In order for mine workers to gain the required experience and recognise these indicators from simulation training, the image resolution and detail of the simulation need to be high and realistic (Stothard *et al*, 2008).

2.1.3.2 Immersion

The level of immersion experienced by a user is the second dimension affecting realism. Immersion is determined by display type (discussed in Section 2.1.1.1), interaction and presence. Interaction with the VE is achieved through the use of input devices which allow the user to freely manipulate objects in the VE using natural motion such as hand gestures. Presence is described by Whitmer, Gerome and Singer (2005) as:

'A psychological state of 'being there' mediated by an environment that engages our senses, captures our attention, and fosters our active involvement. The degree of presence experienced in that environment depends on the fidelity of its sensory components, the nature of the required interactions and tasks, the focus of the user's attention/concentration, and the ease with which the user adapts to the demands of the environment. It also depends on the user's previous experiences and current state.'

In order to create full immersion in VR all three of these aspects need to be addressed.

2.2   VIRTUAL REALITY APPLICATIONS IN EDUCATION

Simulations can play a major role in education as they provide a safe, realistic environment for students to repeat processes in order to easier understand concepts and theories (Onyesolu *et al,* 2013). Virtual reality (VR) has been successful in enhancing student learning in numerous cases. Models created by Sampaio and Henriques (2006) were used to improve student learning in the field of civil engineering. Models were created to encompass two standard building situations. These models allowed students to visualise the construction process in detail that included construction sequence, methodology applied, equipment requirements and to also see how each of these elements interact (Onyesolu *et al,* 2013). This model was adopted for use in Civil Engineering and Architecture courses by the Higher Technical Institute of the University of Lisbon.

Simulations can also provide a means of education in situations where infrastructure may be lacking (Onyesolu *et al*, 2013). Georgiou, Dimitropoulos and Manitsaris (2007) presented a simulation for volumetric analysis experiments in the field of chemistry. The model was designed to interactively simulate these experiments in real-time under the learning conditions in a laboratory. This model was seen as a cost-effective means of promoting chemistry education, especially in situations of distance education (Onyesolu *et al*, 2013).

Onyesolu *et al* (2013) developed a desktop virtual reality model with the intention of determining how it could be best implemented in education. They tested the impact of learning conditions imposed by the three learning theories of instructivism, constructivism and socio-constructivism when teaching fundamentals of networking.

These three learning theories are defined as follows:
- Instructivism: states that knowledge should be transferred directly to the learner from the educator or teacher via instruction. This knowledge is expected to be wholly accepted and not questioned by the learner. (Onyesolu *et al*, 2013)

- Constructivism: also referred to as constructivist theory, is based on the idea that the learner actively constructs his or her own knowledge. The theory states that learning is something the student does, and it is not imposed on him or her. The learner uses individual ideas as tools to understand information presented to him or her by the teacher (Onyesolu *et al*, 2013; Yahaya, 2007 cited in Biggs and Moore, 1993).

- Socio-constructivism: also known as social constructivism emphasizes the importance of culture and context in giving meaning to what happens in society and constructing knowledge from this understanding (Onyesolu *et al*, 2013). In this case, knowledge is derived from social interaction rather than observation (Yahaya, 2007).

Students were grouped into classes and exposed to teaching via these theories. The instructivist group (IG) did not use the simulation, the constructivist group (CG) was shown the simulation by a teacher as a supplement to a lecture and the socio-constructivist (SG) group were provided with the simulation and study guide without a lecture and allowed to interact with each other. Based on the results of the tests conducted by the students, it was seen that there was an increased score with increased interaction with the simulation. With a maximum possible score of 20, the IG students scored lowest among all groups with scores between 8-13, CG students scored the next highest with score between 10-16 and the SG students had the best scores in the test with scores between 14-19. These results show the CG and SG students performed much better than the IG students which indicates the exposure to the simulation had a positive effect on student performance for the CG and SG groups.

Prior implementation of VR in other fields of education shows promise for its use in mining education. Its successful use in a civil engineering environment suggests that it could be adapted to showcase mining processes. A simulation can also provide a means of exposing students to real-life scenarios where circumstances would prove financially or practically difficult. When directly applied to a learning environment, it was seen that test results of students who actively participated in the simulated environment scored better than students who were simply exposed to it and much better than those who were not (Onyesolu *et al*, 2013).

The use of virtual reality technology can assist in bridging the education gap between theoretical classwork and real world processes. Academic staff at the University of Nottingham identified an issue where chemical engineering students would be unable to identify equipment and processes at a full scale industrial plant despite having being theoretically studied in a classroom (Schofield, Lester and Wilson, 2004). In order to address this issue, they decided to develop a simulation of a chemical processing plant in order to provide the students with a more constructivist approach to learning.

Schofield (2012) identified issues that have negative impact on the effective implementation of virtual environments and detract from its educational benefit. The issues identified were:

- viewpoint;
- spatial location;
- realism;
- media mode;
- audio;
- resolution;
- accuracy;
- narrative; and
- lighting.

The issues surrounding where the viewpoint is located mainly depends on the view the user has from their physical location in the simulation. In the chemical plant simulation, the viewpoint chosen was first-person. This was chosen over third-person with the aim of allowing the student to feel immersed and engaged within the simulated environment rather than simply controlling the actions of an avatar (Schofield, Lester and Wilson, 2004). The concept of viewpoint is also linked to spatial location. Schnabel and Kvan (2003) determined that the general public has difficulty correlating their location between 2D and 3D mediums. The benefits of using a simulated environment becomes further evident here as some learners will be able to specify their physical location by referring to a virtual environment rather than attempting to use 2D map (Schofield, 2012).

The use of a 3D virtual world can offer many opportunities to education surrounding design work. Changing educational trends and technological advances have allowed for 3D virtual worlds to contribute as constructivist learning environments (Gül, Gu and Williams, 2008). By implementing a problem solving aspect into a 3D virtual world, a constructivist learning environment is created. Through exploration and manipulation of the environment, as well as the interaction between each student within the environment, opportunities for skill building can take place (Gül, Gu and Williams, 2008).

2.3   UNDERSTANDING THE LEARNING PROCESS

Bell and Fogler (1995) state that students learn best when a variety of teaching methods are used. Furthermore, they state that different teaching methods are effective for different students which indicates that not all students will respond to a teaching method in the same way. The understanding of how a student will respond to a teaching method or how a student learns will allow the educator to use different teaching approaches in order to ensure maximum information transfer and retention. The average retention rates from different teaching and learning methods are shown in Figure 4, from which it can be seen that an average of 75% of knowledge or information is retained when students learn by doing.
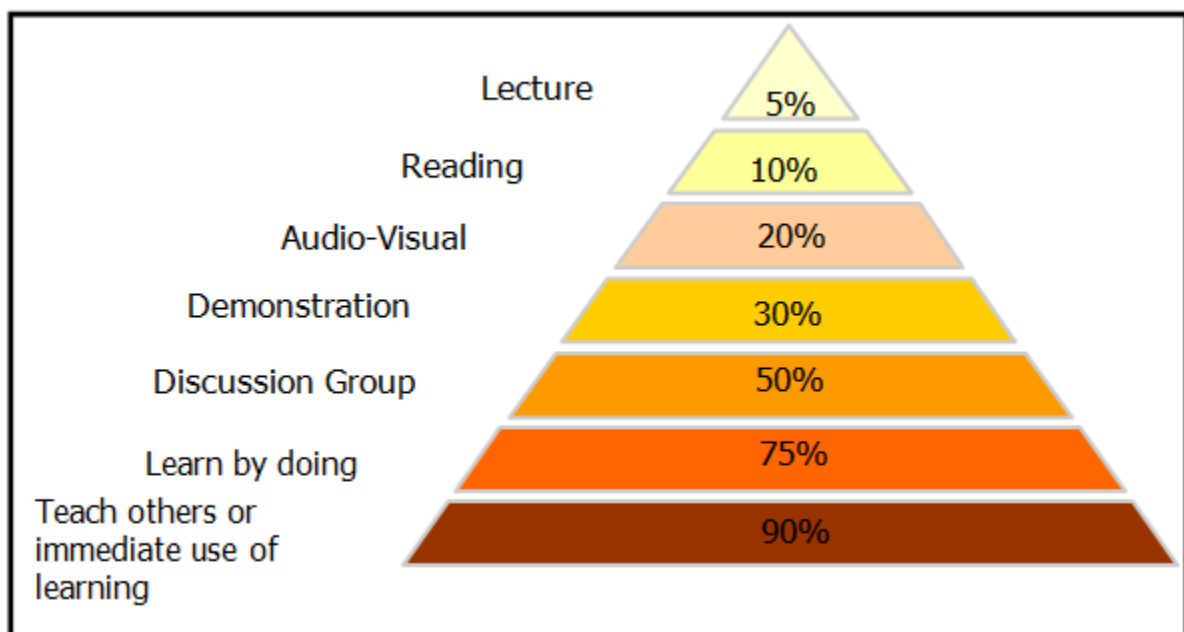
Figure 3. Average Retention Rates (Kizil, 2004)

2.3.1   Constructivism

Yahaya (2007) states that constructivism (also referred to as constructivist theory) refers to the theory that students construct knowledge for themselves. The theory proposes that learning occurs through the construction of knowledge based on surroundings. Students construct meaning while engaging with a new experience and relate this knowledge to their previous experiences (cited in Carnell and Lodge, 2002; Jonassen, 2000). The following three points are emphasized by constructivism:

- People actively construct knowledge for themselves;
- Knowledge is based on categories derived from social interaction not observation; and
- People determine their own knowledge i.e. what they learn. (Yahaya, 2007 cited in Biggs and Moore, 1993).

By knowing how to guide the learning of a student, an environment can be created in which a student can effectively build their own understanding.

2.3.2   Active Engagement in a Constructivist Learning Environment

The constructivist learning view emphasises the dynamic interaction between the student and their **surroundings or environment**. During this interaction the student is said to be actively engaged in the learning process. Five roles of a student actively engaged in a constructivist learning environment were presented by Yahaya (2007) (cited in Bereiter, 2002; Bereiter and Scardamalia, 1996; Scardamalia, 2002). These roles are summarised as:

- The student learns from constructing knowledge through manipulating and interacting with equipment or materials provided to them;
- The student learns with guidance or hands-on learning;
- The student learns through problem solving either individually or in a group;;
- The student gathers information from various research sources to answer any questions arising from the learning process; and
- The student can improve the solutions through group interaction, where students propose initial solutions and resulting discussions and interaction improve these solutions.

These five roles can be summarised as: Interaction, Navigation, Problem-Solving, Research and Optimisation.

2.4   VIRTUAL REALITY IN MINING EDUCATION

One of the key motivations behind the use of VR in education is provided by Yahaya (2007) in his PhD thesis about learning decision making in virtual reality enhanced learning environments and is summarised in the following quote:

"It can be argued that VR can provide the 'transitional interface' between university learning and the workplace allowing transformation of conceptual learning to experimental learning. It promotes learning that lasts by providing a simulated version of real life and allows manipulation that is not available in the normal classroom environment. Tangible and intangible aspects of a corporation can be simulated in this environment which is difficult to produce using other forms of technology."

Pedram, Perez and Dowsett (2013) also state that a successful mining training program should result in the creation of a safer workplace and a more competent workforce, which in turn contributes to more effective management. This infers that a competent graduate mining engineer should contribute to the successful creation of a safe workplace. In order to do this the 'transitional interface' discussed by Yahaya (2007) is required. Figure 4 illustrates the impact of interactive VR education on various aspects of mining operations as described by Pedram, Perez and Dowsett (2013).

Figure 4. Potential Impact of interactive VR based education on various aspects of mining operations (Pedram, Perez and Dowsett, 2013)

Using VR in mining education provides students with the opportunity to be taken to locations that would otherwise be extremely difficult or impossible to gain safe access to in reality. Such an example is illustrated in Figures 5 and 6 which are screenshots taken from the longwall mining simulation available in the Immersive Learning Facility (ILF) at UQ. The ability to look behind the hydraulic shields or get up close to the longwall shearer in a longwall mine provides students with a perspective of longwall mining that cannot be provided in reality.

Figure 5. Longwall mining simulation - view of longwall shearer (VR Space, 2014)
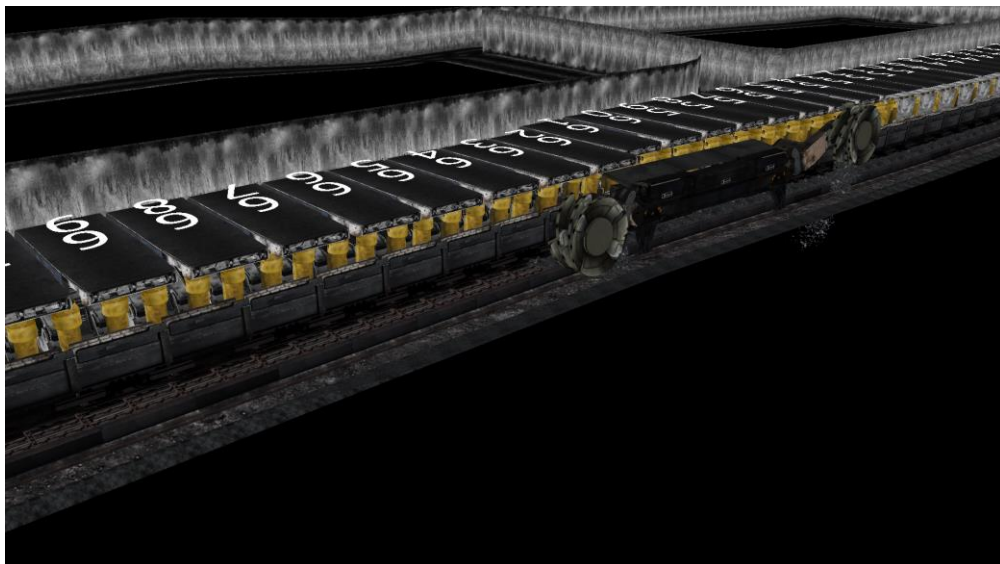
Figure 6. Longwall mining simulation - external view of shearer and hydraulic shields (VR Space, 2014)

Stothard and Laurence (2014) demonstrated an application of VR in mining education via a large-screen simulation visualisation system that presents sustainable mining concepts that must be managed at a mine site surrounded by a national park. The simulation was of the mixed-reality type which included data and information represented graphically and superimposed over real world images, or in this case, digital images. The system utilises, digital 360 degree panoramas, 360 degree video, computer generated 3D models, access to a database of chemical data, video interviews and other directly related information (Stothard and Laurence, 2014).

The system was trialled at the University of New South Wales (UNSW) in the course Mining in a Global Environment and qualitative data was collected. There were 16 participants in the trial who were divided into small groups and provided with an introduction to the simulation and controls, followed by instructions as to their objectives. Qualitative data regarding their experience was collected from participants through a survey which was completed by 12/16 participants.

An analysis of the survey results found that most agreed and strongly agreed that:
- the assignment was challenging but useful;
- working in a group was useful in this module;
- learning through the interactive simulator was enjoyable;
- the simulator was attention grabbing;
- it was easy to follow what was being taught by the simulator; and
- the course was informative and relevant and the course was enjoyable.

The majority who responded disagreed that they prefer standard classroom training (Stothard and Laurence, 2014).

The results from the trial conducted at UNSW and positive results achieved by other authors such as Onyesolu *et al* (2013), Schofield, Lester and Wilson (2004) and Sampaio and Henriques (2006) in applying VR to enhance education indicates that using VR to enhance mining education would have a positive influence on students understanding of mining concepts which would lead to an increase in assessment results.

2.4.1 Constructivist theory as a framework to develop effective VR simulations for mining education

For the purpose of this project constructivist theory was used as a framework for developing VR tutorials and simulations. This implies that the VR simulation developed in this project needed to facilitate the five roles of a student in a constructivist learning environment and therefore allow for the student to:

- Interact;
- Navigate;
- Problem Solve;
- Research; and
- Optimise.

Table 5 provides a description of how the framework dictated the design and content of the VR simulation developed in this project.

TABLE 5.

Using Constructivist theory as a framework for VR simulation design

Constructivist Framework	Associated VR Simulation Design Aspect
Interaction	Integration of the Leap Motion controller in to the VR simulation will allow the student to interact and manipulate objects in the simulation.
Navigation/User Interface	Navigation through simulations will be done using an Xbox controller. The user interface the simulation will be simple and intuitive allowing students to easily navigate through the required virtual spaces either by themselves for hands-on experience or by a facilitator.
Problem Solving	The simulation will be designed to include hazards and other visually identifiable problems which students will be required to solve.
Research	Problems identified in the simulation may require students to research a specific mining related topic in order to determine a solution which they will need to implement in the simulation.
Solution Optimisation	Once their solution has been implemented, students will be required to discuss the outcomes and determine if the solution can be optimised.

From Table 5 it can be seen that the 5 roles of a student in a constructivist learning environment can be facilitated through the use of VR simulations.

2.4.2 Organisations currently undertaking VR simulations in mining

VR mining simulations are currently being used around the world for education and training. Table 6 provides a summary of some of the organisations around the world that currently use or develop VR mining simulations.

TABLE 6.

Organisations Undertaking Simulations in Mining (Mitra and Saydam, 2013)

Organisation	Simulation	Purpose
AIMS	Underground and surface mine operations and equipment	Visualisation, safety, design, risk management, hazard identification and remediation
SIMRAC, South Africa	Underground goldmine stope model	Safety and hazard recognition
Pennsylvania State University, USA	Underground coal mine	Safety and hazard recognition
CSIRO, Australia	Underground coal mine data, distributive collaborative immersive VR framework and remotely monitoring underground equipment	Web based disparate mine data visualisation, VR applications on collaborative scenarios
NIOSH, USA	Underground coal mine	Hazard identification and remediation
MIRARCO, Canada	Underground mine	Mine machinery, geology, geochemistry
MISC, Australia	Surface environment	Hazard awareness
THALES	Underground hard rock	Teleremote control
DMT, Germany	Operator training	Equipment operation training and visualisation
Tshwane University of Technology, South Africa	Underground platinum mine	Hazard identification and remediation
University of New South Wales, Australia	Underground coal mining, surface coal mining, uranium mining	Visualisation, hazard training, safe work procedures, environmental and social impacts, equipment training, site investigation
University of Queensland, Australia	Surface and underground mining	Visualisation, equipment operation, experimental analysis, hazard spotting.
Virginia Tech, USA	Surface and underground mining	Conveyor system training, preshift inspection of haul trucks

The University of New South Wales (UNSW) is currently Australia's leading institution in VR mining education. Their VR Suite was developed in conjunction with industry partners and is known as the Advanced Visualisation and Interaction Environment

(AVIE). The system makes use of the iCinema facility at UNSW which comprises of a 360-degree cylindrical screen, four metres high and ten metres in diameter which uses six 3D stereoscopic projectors to produce a fully immersive experience (see Figure 7). It also features an intelligent vision-based interaction and motion tracking system which can accurately track the spatial position and movements of up to thirty people (UNSW, 2014).
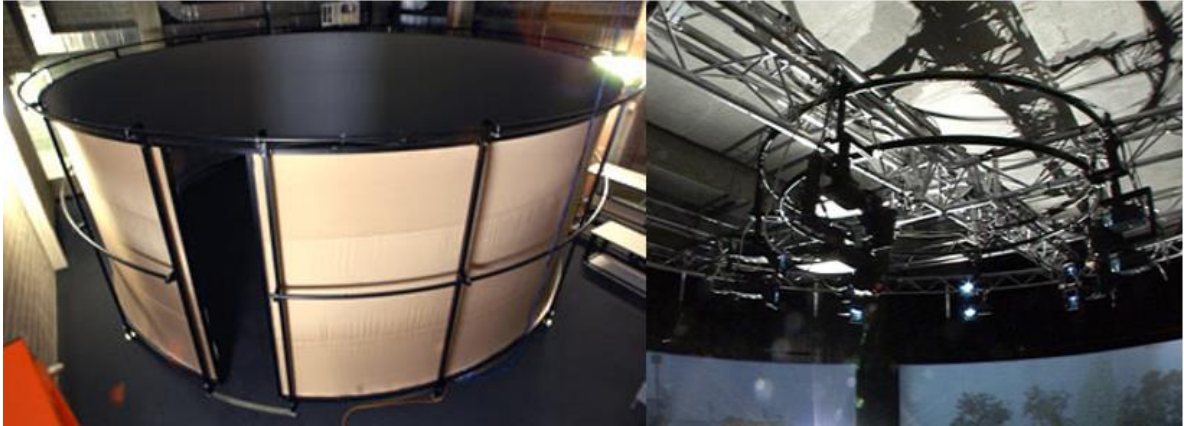
Figure 7. AVIE External view and Projector Set up

Table 7 lists the modules which have been developed and are available for use with UNSW VR Suite as per the UNSW website. Figure 8 illustrates the VR Suite in use.

TABLE 7.
UNSW VR Suite Modules (UNSW, 2014)

Module	Description
Self-escape	Students are presented with an emergency situation within a 3D-representaton of a longwall mine and various transport roadways. Split-second decisions need to be made while a team of miners is evacuated.
Mining in a Global Environment	This module transports students to the vast blue-skies of Kakadu National Park (where they can walk through 360-degree panoramas of the Ranger Mine and its local environment) to undertake feasibility testing and to take a hands-on approach to project planning.

Outburst management	This modules presents a detailed virtual reproduction of an often-fatal outburst event, allowing students to safely enter this 'worst-case scenario', trace the events that led to the outburst, and then manage their teams through the aftermath.
3D terrain exploration	Students are in the driving seat for this module. They choose possible surface environments that might exist near a mineral deposit. Then an ore-body is placed underneath the selected terrain-scenario to instantly reveal the depth, orientation, dip and rock characteristics.
ViMINE	The ViMINE Module 1 scenario activity is on mining methods selection for both 1st and 3rd Year students. Currently the students learn how to select mining methods through several separate activities, without the benefit of an integrated simulation. At the end of the course, the students are assessed in the form of a written report and/or presentation and in a final exam, in which they are expected to demonstrate an integrated understanding of the selection process and its potential outcomes.

Figure 8. UNSW VR Suite demonstration (UNSW, 2014)

2.4.3 UQ Immersive Learning Facility

In 2014 the Immersive Learning Facility (ILF) in the Advanced Engineering Building (AEB) at the University of Queensland (UQ) was opened. The facility comprises of a

180 degree curved screen and three Digital Projection Titan 800 projectors. This system when combined with 3D glasses produces a semi-immersive experience for the user. The system can be switched between two modes via an AMX touch panel (Figure 9). Simulator mode, shown in Figure 10, switches to three rack mounted workstations (1 for each projector) and is used to run an open cut and an underground coal mine simulation (Figures 11 and 12). These simulations can be run in either 2D or 3D. The three workstations running the VR Space simulations are Dell Precision R7610 rack mounted workstations, each with two 3.3 GHz Intel Xeon quad-core E5-2643 CPUs, 16GB RAM and NVidia Quadro K5000 graphics cards with the optional Stereo (3-pin Mini-DIN) daughter card. Each of the workstations also has an Nvidia Quadro Sync card.

Figure 9. AMX Touch Panel

Figure 10. ILF in Simulator mode

Figure 11. Open cut coal simulation

Figure 12. Underground coal simulation of Carborough Downs Coal Mine. Site topography (top). View from longwall shearer (bottom).

The second mode of the system switches to an additional Dell Precision R7610 workstation for running ImmersaView VADAAR. The VADAAR workstation is connected to all three projectors and operated in an extended desktop configuration with the warping blending handled by the graphics card and projectors. Figure 13 shows the system in VADAAR mode.

Figure 13. ILF in VADAAR mode

The visualisation system in the ILF can be classified as a Class 5 display system as per the "Classification of mixed reality display systems" provided by Stothard *et al* (2013). It was used in this project to provide the semi-immersive experience required using the VADAAR workstation. It was deemed most suitable as it allowed for group discussion and interaction while students interacted with the VR simulation.

3. METHODOLOGY

The approach taken in this project was divided into three phases. Namely:

1. Simulation Development (Design and Construction):

    Phase 1 involved the design and construction of an open cut coal mine VR simulation in the game engine Unity to be used in the ILF at UQ.

2. Implementation and Data collection:

    Phase 2 used the simulation developed in Phase 1 to conduct a paired data observational study with fourth year mining undergraduates that was designed to measure the difference in assessment results between a traditional assignment and a VR-aided assignment, from which data was collected. An online, Likert Scale survey was also conducted to assess the students' experience.

3. Data Analysis and Results:

    Phase 3 included the analysis of the data collected using a paired t-test to determine the absolute difference and relative increase in student results as well as statistical significance. An analysis of the survey results was also completed.

This was an iterative process which initially involved the development of the mining simulation followed by the creation of the assignment which then dictated aspects of the mining simulation that needed to be adjusted or added in. It was decided that the observational study would be run in the risk management section of the fourth-year mining course: Mine Management (UQ course code MINE4121).

Sections 4, 5 and 6 provide further details of the three phases of the project.

4.   SIMULATION DEVELOPMENT

4.1   DESIGN AND CONSTRUCTION

This phase of the project involved the design and construction of the mining simulation which was named Dynamic Slope Failure Risk Management (DSFRM) on completion.

4.1.1   Design and Modelling

The conceptual design of the simulation was done with the collaborative efforts of mining academics in order to ensure all the required mining concepts were correctly simulated. A discussion regarding the content of the simulation and the associated mining related concepts with Prof. Peter Knights resulted in the following simulation design aspects:

- The simulation would be set in an open cut coal mine which was monitoring a potential slope failure in the highwall over the duration of a week;
- The failure zone would be visually identifiable and have a data feed to show the rate of movement each hour and the cumulative slope displacement which will update every hour according to the in-game timescale;
- The monitored slope would fail at some point during the simulation which would be preceded by a spike in Rate of Movement (RoM) and an exponential increase in the cumulative slope displacement curve;
- The simulation would need to use a timescale which allowed a week in-game to be compressed into one and a half hours in reality.
- The time of day would need to update according to the in-game timescale i.e. there would be day/night cycles and fluctuation in weather; and
- There would be a significant rain event which would result in increased slope movement activity ~24 hours after the event.

Once the basis of the simulation was determined the next step was to design the mine and model it in 3DS Max. Due to the time constraints on the project it was not feasible to design and model a new mine site. In order to simplify this process an existing open cut coal mine model was acquired from VR Space which was used as the basis of the simulation. The model included the full mine site and low detail mining equipment but

required some modification to satisfy the requirements of the simulation. The modification of the model included:

- Replacement of existing mining equipment 3D models with higher detail, optimised 3D models;
- Modelling and animation of a wedge failure in the highwall; and
- Modelling of an active coal mining area below the wedge failure zone.

4.1.1.1 Equipment Model Optimisation

In 3D modelling, model optimisation refers to reducing the polygon count and number of meshes in the 3D model. This has a direct effect on the performance of the simulation by decreasing the number of polygons the GPU has to render and therefore increasing the frame-rate of the simulation. A detailed equipment model set was purchased from the 3D model site, Turbosquid (Turbosquid, 2015). These detailed 3D models shown in Figure 14 needed to be optimised to decrease their polygon count so as to be suitable for use in the simulation.

Figure 14. Mining Equipment 3D Models (TurboSquid, 2014)

The polygon count of the models used has a direct effect on the performance (frame-rate) of the simulation, it was therefore necessary to optimise the models (i.e. reduce polygon count) to ensure the simulation could be run not only on the high-end workstations in the ILF but on desktop PC's as well. The optimisation of the models was done in 3DS Max using the following process:

- Import model into 3DS Max;

- Select sub-objects to be joined and use the "attach" function to join components of model to create fewer sub-objects which could be more easily worked with;
- Apply "Pro-Optimiser" modifier to joined model and reduce polygon count by 30-50%; and
- Export model with materials in FBX format.

Figure 15 and Figure 16 show the difference in detail and polygon count produced by polygon reduction for a model of the Liebherr T282C haul truck reducing the count from ~900,000 to ~545,000.
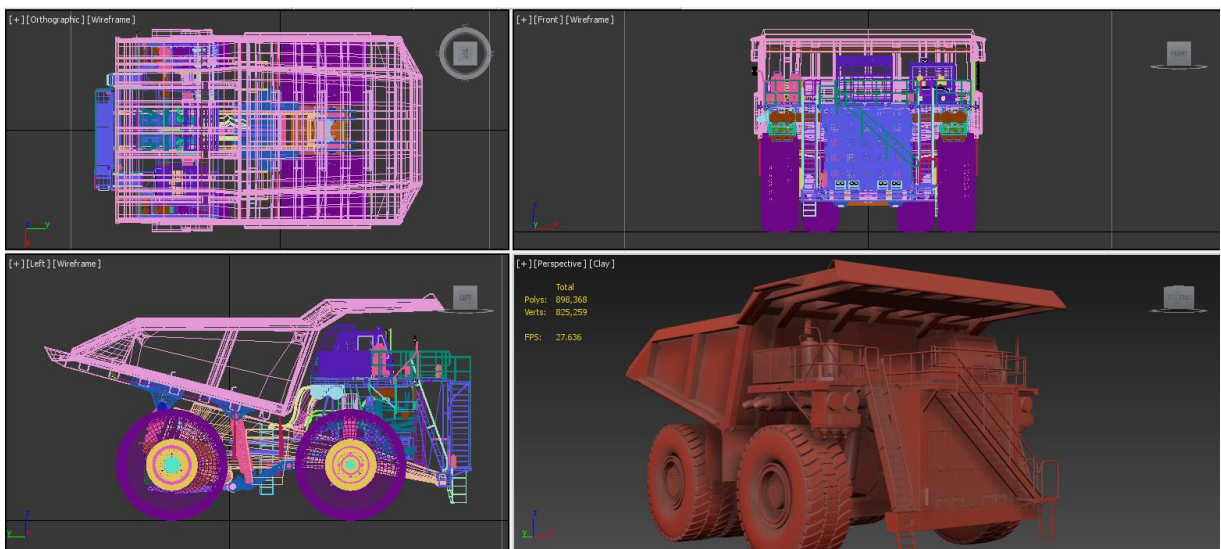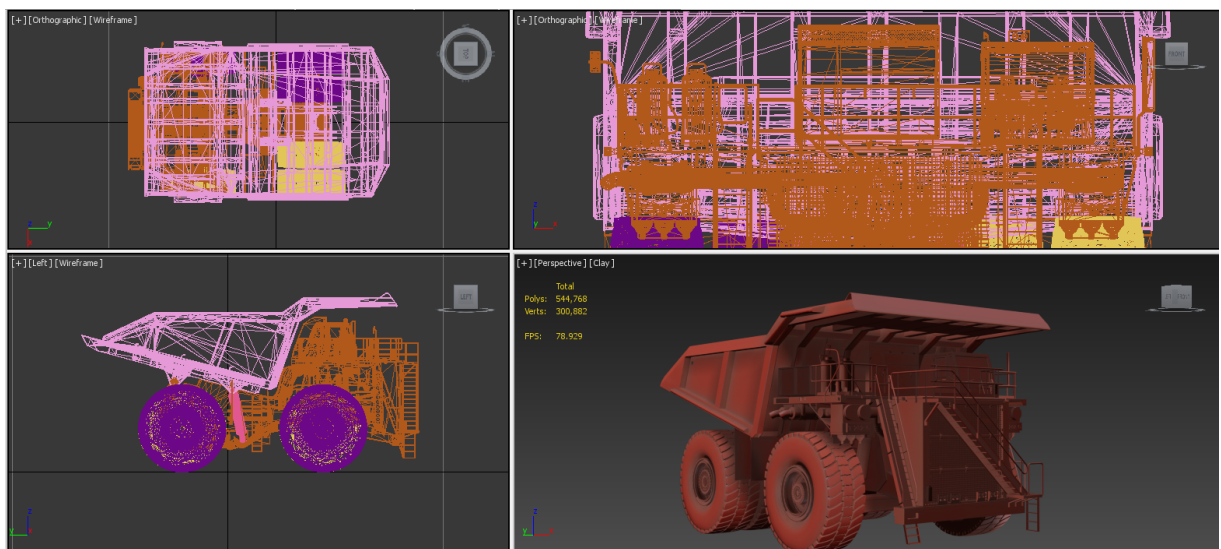

Figure 15. Pre-optimisation

Figure 16. Post-optimisation

This was done for the 4100XPC rope shovel, R9800 hydraulic excavator and T282C haul truck 3D models.

4.1.1.2 Wedge Failure Modelling and Animation

A key component of the developed simulation was the inclusion of a wedge failure animation to create a realistic representation of the level of risk and associated consequence of the scenario (slope failure). In order to create a realistic slope failure simulation scenario, an accurate animation of a wedge failure needed to be created. This was done using a plugin for 3DS Max known as RayFire.

Rayfire is a plugin for 3DS Max that is used for fragmentation and animation of objects to produce realistic blast or impact animations which react either under gravity or some external force produced by another moving object. The plugin is used commercially for games and movie development to create ballistics and demolition animations (Rayfire Studios, 2015). Figure 17 shows an example of fragmentation achieved using Rayfire for 3DS Max. The object in the figure has been sub-divided into smaller objects using or "fragments" using Irregular Voronoi fragmentation to produce an object that appears to have shattered. Other fragmentation options are available in Rayfire which produced different fragmentation patterns depending on the user requirements.
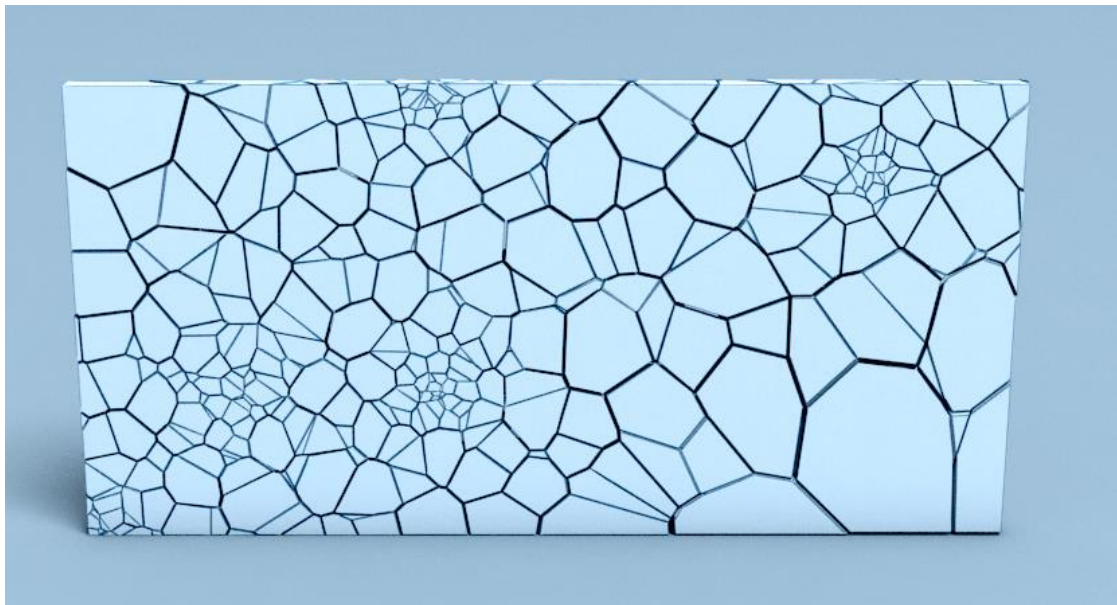
Figure 17. Rayfire Irregular Voronoi Fragmentation (Rayfire Studios, 2015)

To create the highwall failure the following steps were taken:
- Import open cut mine model (OC model) into 3DS Max;

- Choose area on highwall for failure zone

- Cut wedge into existing highwall using 3DS Max modelling tools as separate object;

- Fragment wedge object using Rayfire;

- Animate wedge object using Rayfire for 3DS max; and

- Export OC model including animation as FBX for use in Unity.

Figures 18 to 21 illustrate the workflow used to create the wedge failure.
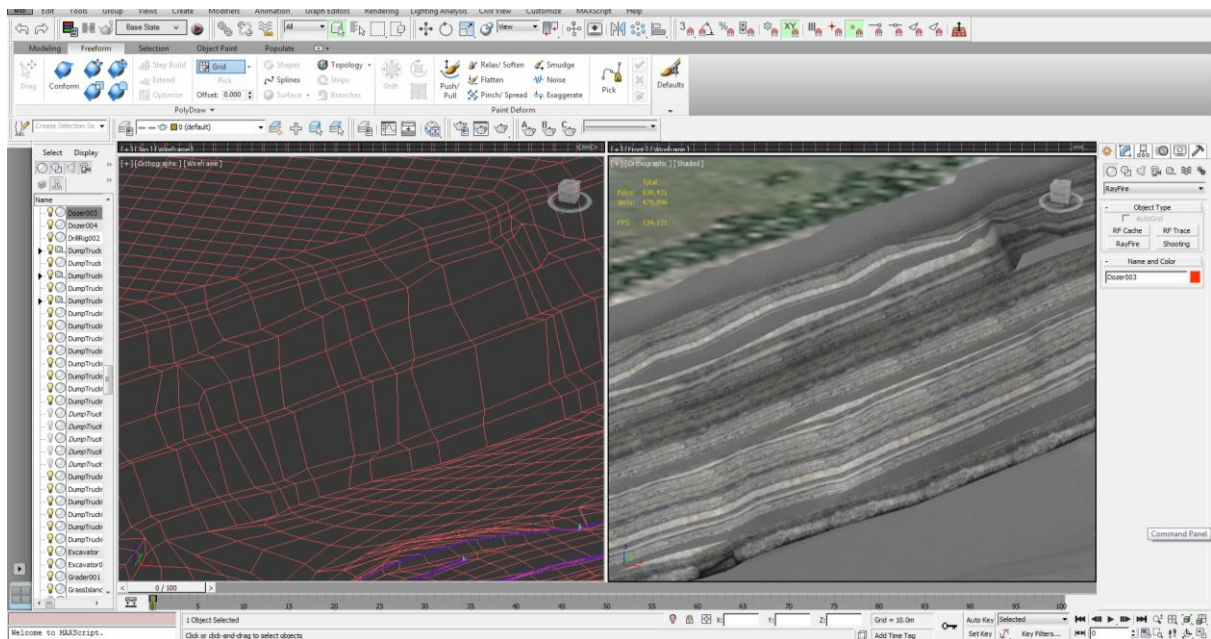
Figure 18. Selected highwall section for failure zone.
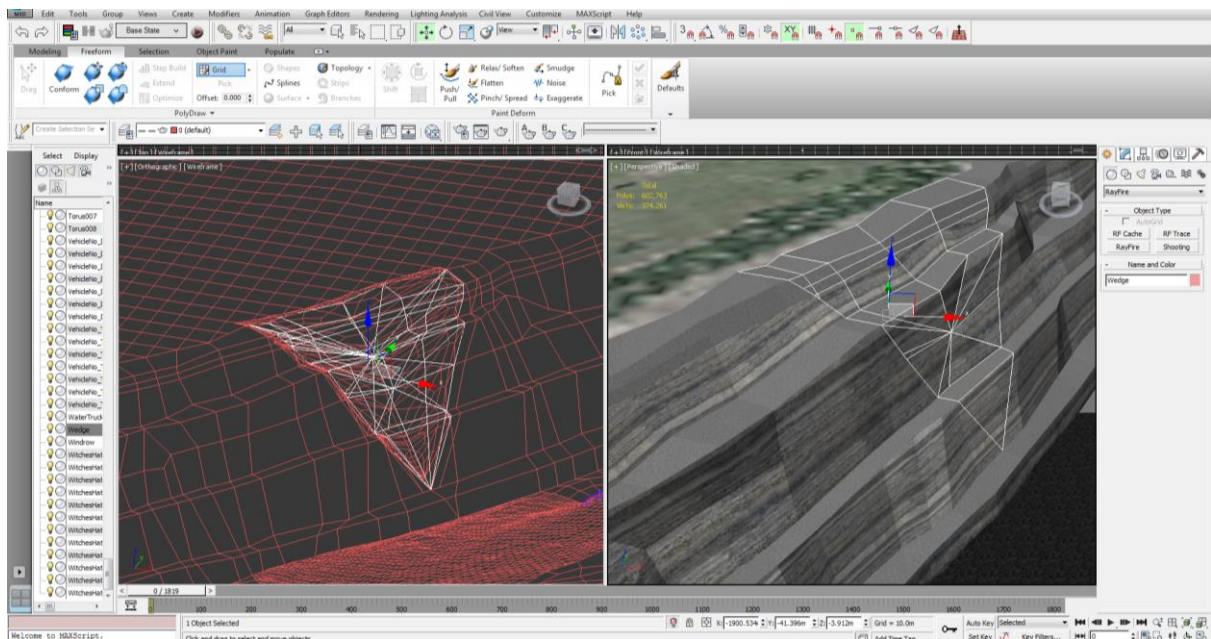
Figure 19. Cut wedge into highwall.
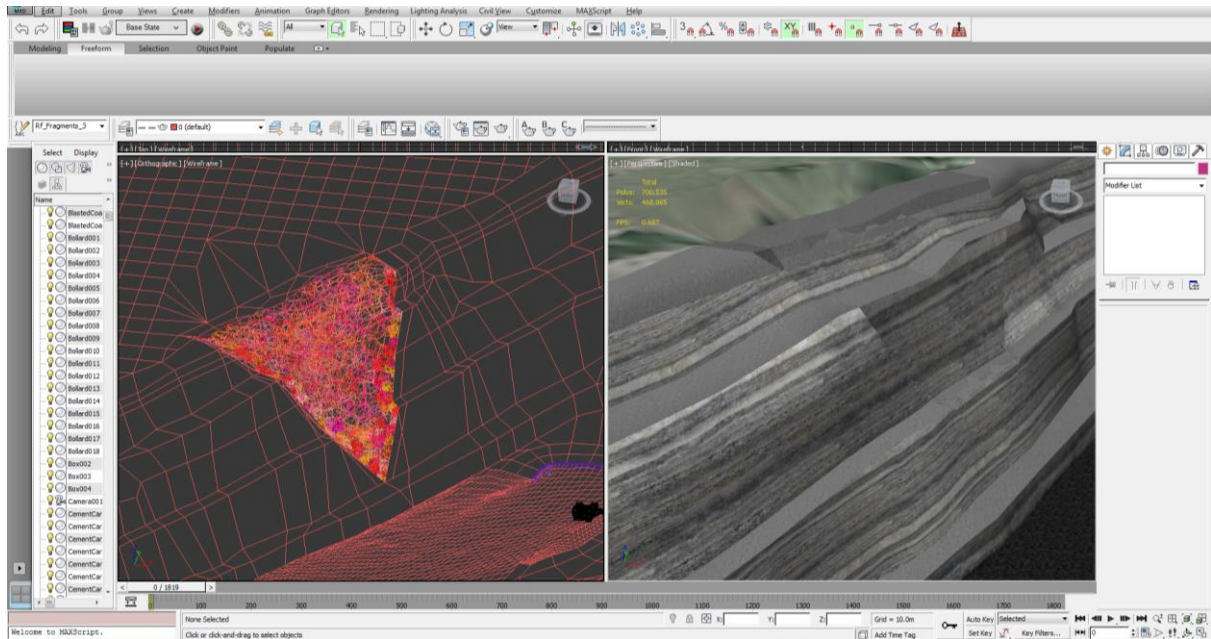
Figure 20. Fragment created wedge object using Rayfire
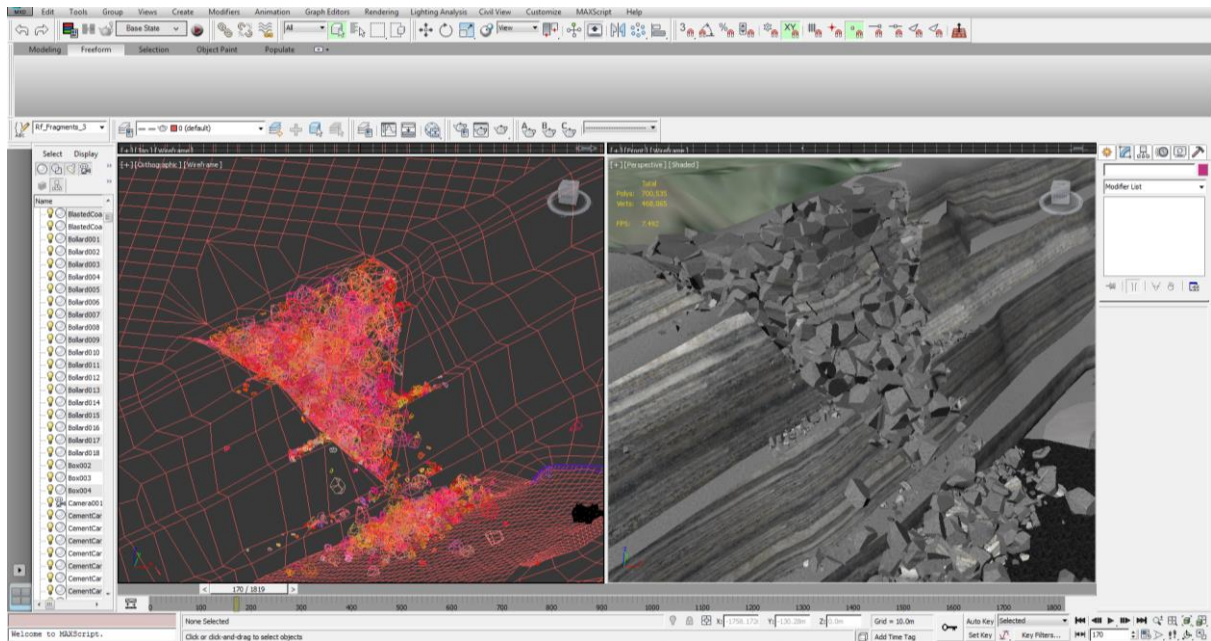
Figure 21. Animate failure of fragmented wedge object.

4.1.1.3 Active Coal Mining Area

A blasted coal seam being mined was added to the existing open cut model in order to create a realistic coal mining scenario. Figure 22 shows the original model without the blasted coal. The mining operation associated with the seam was positioned directly below the projected highwall failure zone as shown in Figure 23.

In order to model the coal seam, a series of polygons below the wedge failure zone were selected and duplicated as new object. The new object which formed a plane

was edited using a polygon modifier which produced a bumpy plane like that of a blasted coal strip by distorting the selected plane. A realistic blasted coal texture was then applied to the object which produced the required blasted coal strip.
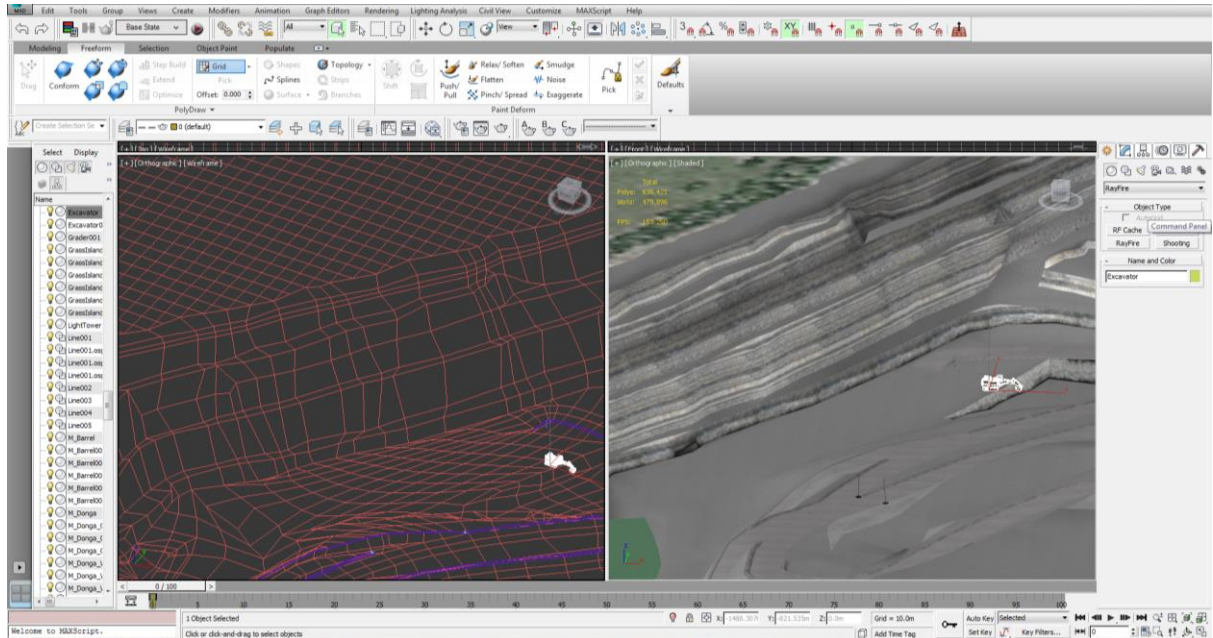
Figure 22. Original model without coal.
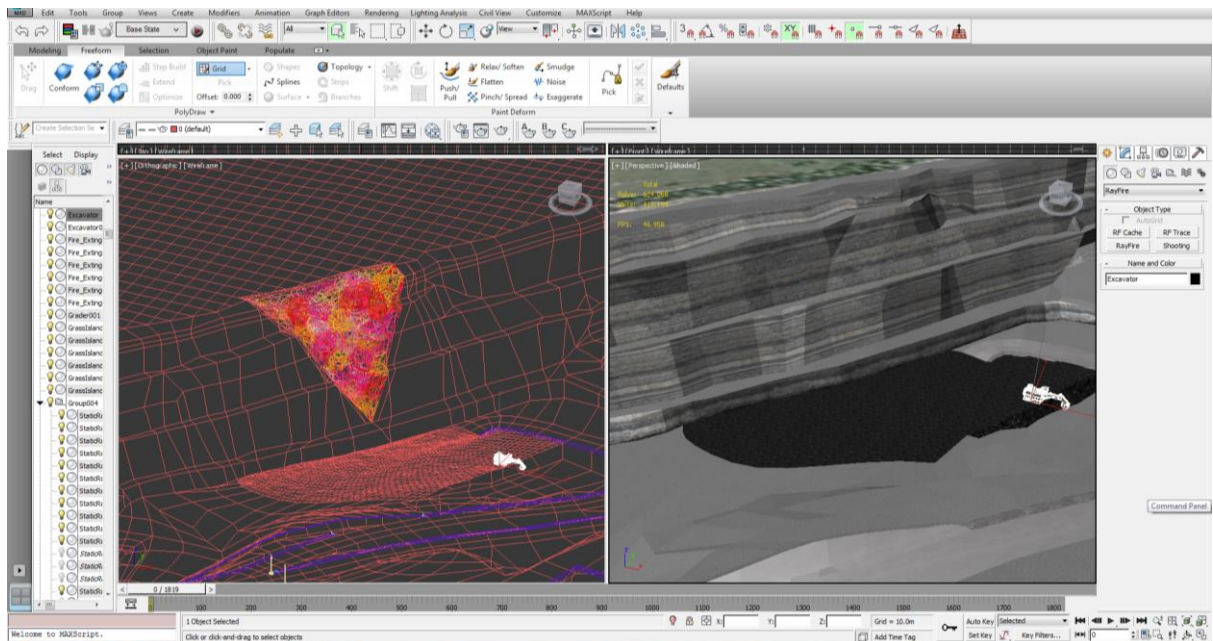
Figure 23. Resulting blasted coal strip.

4.1.2 Construction

The construction of the simulation was done in the game engine, Unity. Initially it was thought that the custom version of OpenSceneGraph (OSG) from VR Space would be used but after gaining a deeper understanding of the development requirements it was

decided that Unity would be used. The decision to use Unity as opposed to VR Space's customised version of OSG was made based on the following key factors:

- Unity has a library of 3rd party integrations available in the Unity Asset Store;

- Unity includes visual editor for debugging;

- Faster iterations - Unity does need to build the scene before running;

- OSG needs to be compiled before operation whereas Unity only requires to be installed and can be used straight away;

- Unity allows for multi-platform deployment allowing for future simulations to be deployed on other platforms such as Android, iPhone or other gaming consoles;

- Unity 5 includes PBR (Physically Based Rendering) which allows for creation of photo-realistic materials;

- Unity is easier to use for amateur developers who don't have much development experience as opposed to OSG which requires the user to be competent with C++.

This section provides details of the processes and tools used for constructing the simulation in Unity.

4.1.2.1 Simulation Logic

The simulation was designed to provide the user with an experience similar to that of an "open world" game (e.g. Legend of Zelda, Grand Theft Auto). "Open World" is a term for video games where a player can move freely through a virtual world and is given considerable freedom in choosing how or when to approach objectives, as opposed to other computer games that have a more linear structure or are instructive, requiring users to complete a predefined sequence of objectives.

In order to create an "open world" simulation there were numerous operations that the simulation need to perform autonomously. These operations included:

- Altering time of day (day-night cycles):
  As the simulation was designed to run over a period of a week, the change in time of day or day-night cycle was required to create a realistic virtual environment. Two options were investigated to setup the cycles: Procedural and

6-sided skyboxes. Based on the availability of HDR skyboxes from the Unity asset store, it was decided that the 6-sided skybox would be used.

The day-night cycles were created by blending skyboxes in Unity. Skyboxes are a wrapper around the entire scene that shows what the world looks like beyond your geometry. Two scripts were written to achieve the required day-night cycles and the variation in weather each day. The first script controls the blending of skyboxes for each day to differentiate day from night and weather changes such as the progression to overcast prior to a rain event.

The second script controls the change of day over the 7 day period which allows for variation in weather from day to day. Both scripts were written to include a timescale that could be modified by an integer input. This allowed the in-game timescale to be controlled while in the simulation. A timescale of 112 was used to compress a week in-game to 1.5 hours in reality

(i.e. $\frac{7*24}{1.5} = 112$).

Figure 24 to Figure 27 show the blending of skyboxes for a single day-night cycle.
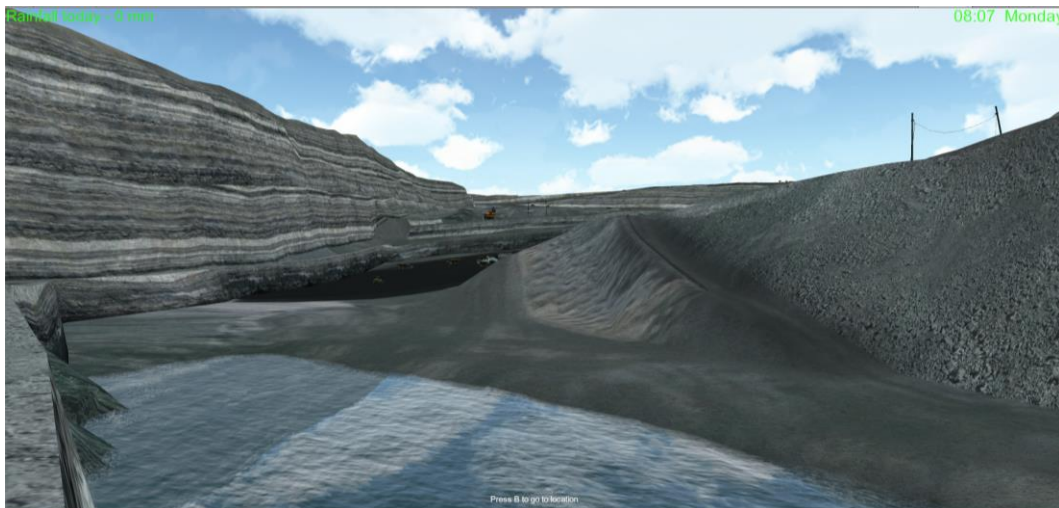
Figure 24. Time of day: morning
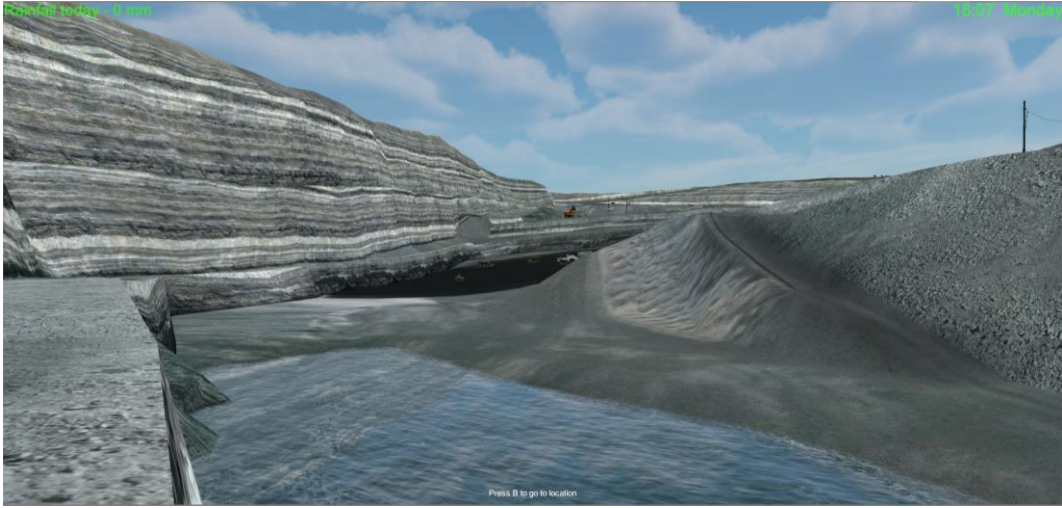
Figure 25. Time of day: midday
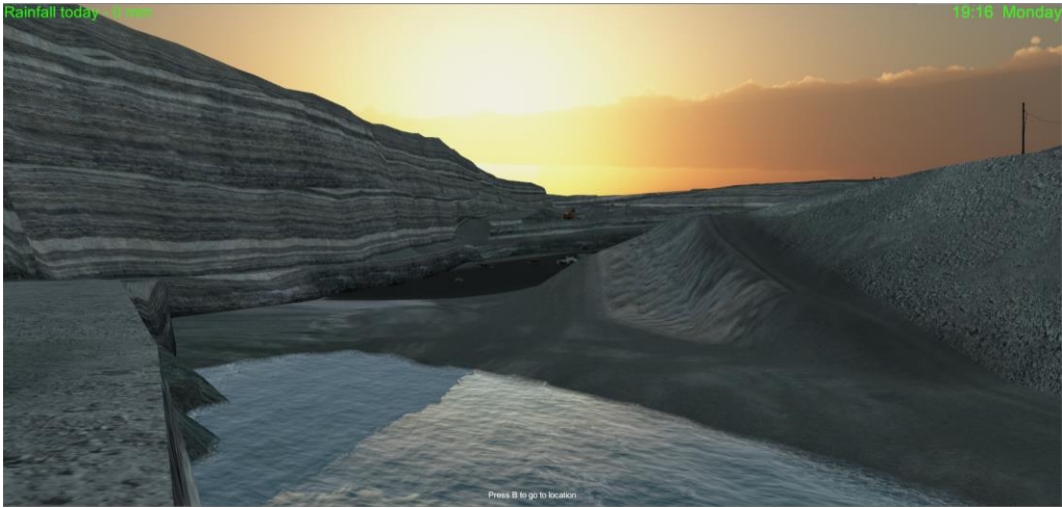
Figure 26. Time of day: afternoon/dusk
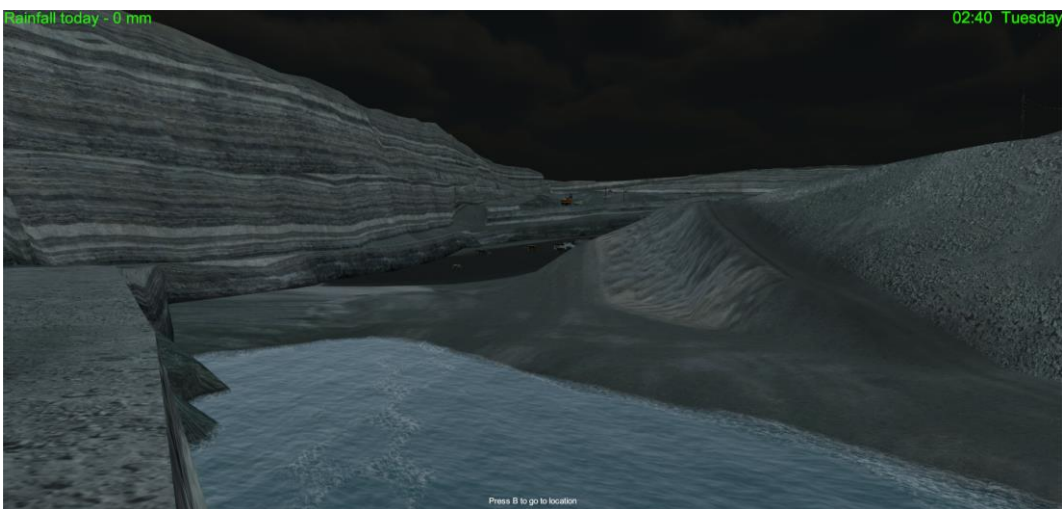
Figure 27. Time of day: night

- Highwall Wedge Failure:

  A data set was acquired from Dr. Zhongwei Chen, who is a geotechnical engineering lecturer from the School of Mechanical and Mining Engineering at UQ. This provided slope displacement measurements over a week period for five monitoring points. This data was processed using Microsoft Excel to produce a series of cumulative slope displacement graphs for each hour. Using the data, the average RoM each hour for each monitoring point was also calculated and used to update the RoM in-game. A script was written which triggered the wedge failure animation when the graph showed imminent failure according to the data set used as shown in Figure 28.
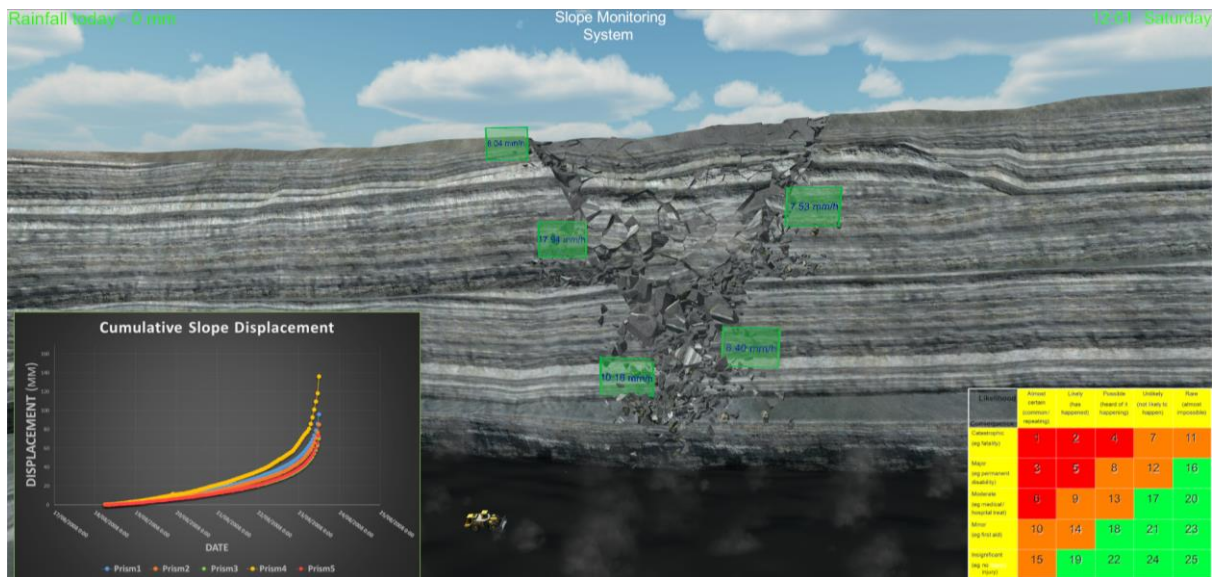
Figure 28. Highwall failure in-game.

- Updating of monitoring points and cumulative slope displacement graphs: In order to have the rate of movement update every hour according to the in-game time scale, a script was written which updates the text component of the canvas game-object linked to each prism monitoring point each hour in-game. The rates of movement for each point were copied into an array of strings (text) containing the rates of movement for each point every hour. This could be read by the script to provide the text for each update. For the graph updates a script was written which takes the image of the required graph from an array of images containing all the graphs and updates the image component of the slope displacement canvas each hour in-game.

4.1.2.2 C# Scripts

The logic explained previously required a number of C# scripts to be written and attached to the relevant game-objects in order to implement the logic. As such, there was a requirement to learn the basics of programming in C#. This was made relatively simply by the availability of the Unity scripting API tutorials available online. Table 8 shows the scripts that were written and their associated function.

TABLE 8.
C# Scripts for DSFRM

Script	*Function/Use*
ChangeDay.cs	Switch between days
ChangeSkybox.cs	Control skybox blending and daily timescale
EnableDusttorm.cs	Enable dust particle emitter on slope failure
InfoButtons.cs	Show/hide information boards
JumpTo4100XPC.cs	Overburden removal navigation shortcut
JumpToLookOut.cs	Slope viewing point navigation shortcut
JumpToR9800.cs	Coal mining area navigation shortcut
Menus.cs	Control in-game menu
PrismPtsUpdate.cs	Update prism monitoring points
RainFallUpdate.cs	Update daily rainfall
SelectHands.cs	Controls hand model selection
ShowSSRPoints.cs	Shows monitoring points when in "Slope Monitoring Mode"
SlopeGraphUpdate.cs	Update cumulative slope displacement graphs
SwitchToTruck.cs	Switch between Modes
WedgeAnimation.cs	Trigger wedge failure animation as required

4.1.2.3 Leap Motion Integration

The integration of the leap motion controller was required to satisfy the need for interaction outlined by the constructivist framework. The leap motion controller provided a means of interacting with objects on the virtual mine site using one's hands. The design behind the integration focussed on scroll boards for providing the user with useful/helpful information and interaction buttons which triggered a pre-defined action such as a navigation shortcut or providing the user with additional information or as shown in Figure 29. and Figure 30.

Figure 29. Interaction button un-pressed.

Figure 30. Interaction button pressed

4.1.2.4 First Person Mode

First-person mode is the default mode when the simulation is started and allows the user to navigate through the mine site from a first-person perspective. In addition to this the user can use their hands to interact with scrollboards and toggle buttons around the mine site. This made possible through the use of a Leap Motion Controller.

4.1.2.5 Truck Mode

The inclusion of "truck mode" was done so as a supplementary activity that allowed the user to drive a haul truck (T282C) from both a third-person and first-person view.

This was intended to provide students with an idea of the field of view seen by an operator as well as the length of time taken to complete a single haulage cycle. Figure 31 and Figure 32 show "Truck Mode".

Figure 31. Truck Mode 3rd person view.

Figure 32. First person/driver view.

4.1.2.6 Slope Monitoring Mode

Slope monitoring mode brings up a virtual camera hovering above the projected failure zone with a cumulative slope displacement graph and likelihood-consequence matrix shown as a HUD. In addition to this the prism monitoring points are visible with their RoM in millimetres per hour shown as well (Figure 33). The slope displacement graph

and prism point RoMs update every hour in-game according to the movement of the slope define by the data set used.
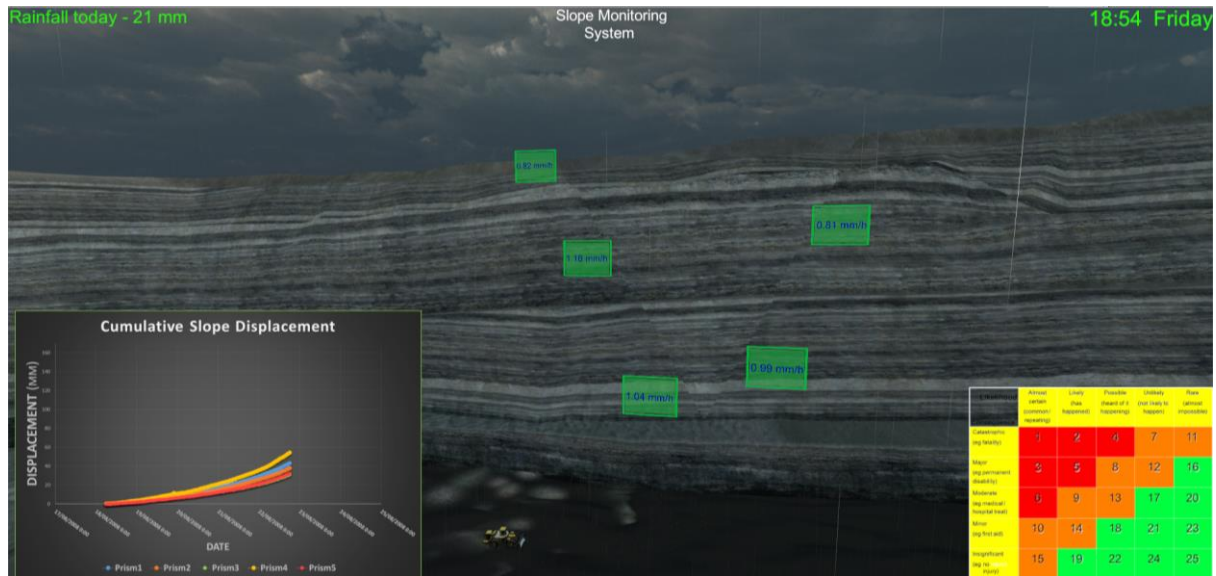
Figure 33. Slope monitoring system

4.1.2.7 User Interface and controls

The when designing the User Interface (UI) of the simulation the following aspects were considered:

- Ease of use (Simplicity);
- User's prior simulation experience.

The user interface was designed to replicate the graphical user interface from popular video games so as to be easy to use for experienced users, and simple to learn for inexperienced users. It therefore needed to allow the user to bring up an in-game menu which provided options for (see Figure 34):

- Returning to the simulation
- Viewing the user controls (gamepad);
- Viewing the weather forecast for the current week;
- Changing the timescale;
- Exiting the simulation.

Figure 34. In-game menu.

This was done using the Unity UI system. A series of canvas (windows that hold UI elements such as buttons, text and images in Unity as seen in Figure 34) were created which could be shown or hidden according to a predefined navigation loop.

The control system for the simulation includes a combination of mouse and keyboard inputs or an Xbox controller (gamepad). The Leap Motion is used in both control scenarios to allow hand interaction with leap objects in the simulation. The user controls for the Xbox controller is illustrated in Figure 35 while the mouse and keyboard controls can be found in Appendix B.
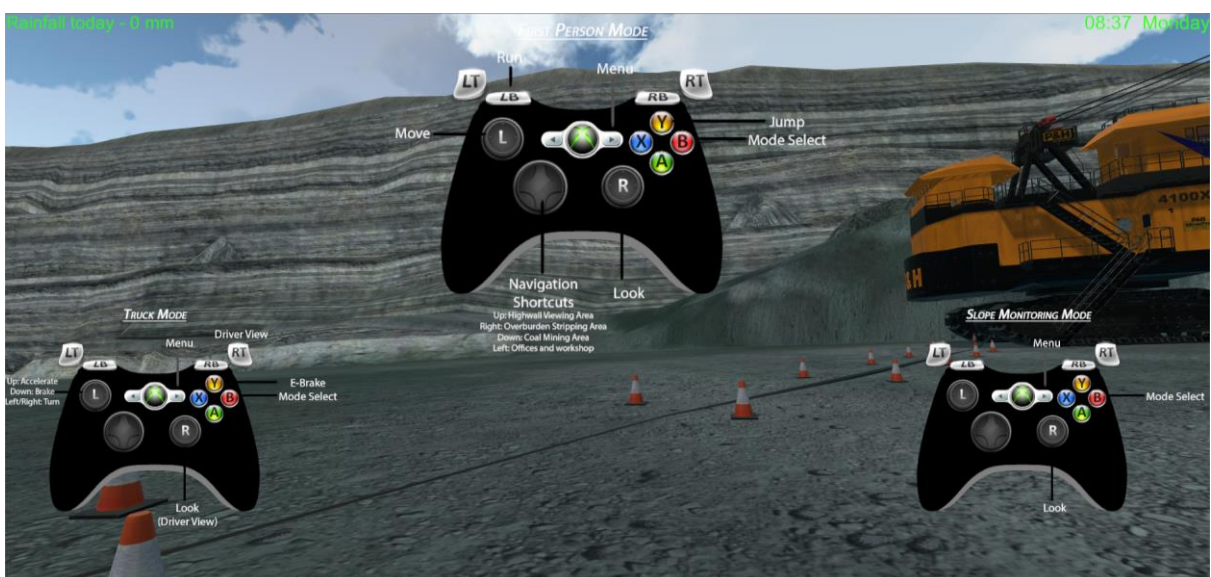
Figure 35. Xbox controls

In order to allow the user to easily move across the virtual mine site without having to travel large distances; four locations were chosen which the user could navigate to using navigation shortcut keys on the gamepad. These locations were chosen to be:

- Offices and workshop;
- Highwall viewing area;
- Overburden Removal; and
- Coal Mining Area.

These locations were mapped to the gamepad direction pad as the shortcuts or the numerical keys 1 – 4 on the keyboard.

4.1.2.8 Oculus DK2 Compatibility

The resulting simulation – Dynamic Slope Failure Risk Management was designed for use in the ILF on the semi-immersive curved screen. A version of the simulation that runs on the Oculus DK2 head mounted display was also created which allowed the user to be fully immersed in the virtual mine and have the use of their hands through integration of the Leap Motion controller. However, due to a lack of time and hardware limitations the DK2 version was not used or tested with students.

5. SIMULATION IMPLEMENTATION AND DATA COLLECTION

Once the design and construction phase was completed the implementation and data collection phase began. This phase involved using the developed simulation (DSFRM) to conduct a paired-data observational study with fourth year undergraduate mining students in the course Mine Management. This section will provide the details of how the observational study was designed and conducted to collect the required data for analysis.

5.1 DATA COLLECTION METHOD

A paired-data observational study was chosen as the means of collecting data to quantitatively analyse the difference in assessment results between traditional and VR-aided assessment. The study was designed to measure the mean difference in assessment results while only changing the medium through which the assessment was presented. With this in mind the designed study called for students to be issued with a written assessment piece which they were allowed a week to complete. After submission of the written assessment the students would then be taken through a VR simulation and asked to amend their initial submission and re-submit for assessment. The results of each submission would then be analysed and compared using a paired t-test to determine the difference in the means and its significance.

Qualitative data regarding the students' experience and perceived advantages/disadvantages of the VR session over the written assessment was collected through the use of an online survey conducted after the VR session. Feedback from the assistant tutor present during the VR-session was also collected in order to provide a third party observation.

5.1.1 Limitations

It is important to acknowledge the limitations of the study and thereby determine improvements that can be made to increase the accuracy of results obtained by any further studies conducted. The limitations of this study include:

- No control group:

  The study did not have a control group against which the results of the VR assessment could be compared directly. It was initially thought that the class could be split into two groups (A and B). This would allow group A to complete the written assessment while having group B simultaneously complete the VR assessment. After completing their respective assessments, the groups would then swap i.e. group A would complete the VR assessment and group B would complete the written assessment. This would allow the written assessment from group A to act as a control against which the results of group B VR assessment could be compared. Unfortunately, this was not possible given the assessment schedule of students participating in the course. It would also not have provided a true control as the groups could not be chosen to allow for equal intellectual capability in both groups which could have resulted in the group with higher intellect having a greater influence on results.

- Small sample population:

  The sample size for this study was nineteen groups. While the total class size was 76, the assessment was a group based activity. To increase the accuracy of any future studies, it is recommended that an individual assignment be used as the basis of the study with a larger population size (100+) which would increase accuracy of results obtained.

- Prior understanding: As students were provided with the same assessment task in both Part 1 and Part 2, it can be argued that the results obtained would have a level of bias toward the VR result as students had completed the TARP exercise in Part 1. This would provide them with an inherent advantage as they were essentially redoing Part 1 in a VR session with a short deadline.

5.1.2 MINE4121 & Assignment 4

Mine Management (UQ Course Code:MINE4121) is a fourth-year mining course that was coordinated by Prof. Peter Knights and run by Dr. Jeff Rowlands in semester two, 2015. The course description as per the UQ website is as follows:

"Theory & process of management, financial & management information systems, human behaviour, IR, contracts & contractors, joint ventures, international issues, professional ethics, team dynamics. Mining law. Applications in risk management. Hazards in coal & metal mines. Emergency response strategies." (UQ, 2015)

The risk management section of this course was deemed the most suitable for running the study. The class of 76 students were divided into groups of four. This created nineteen groups.

5.1.2.1 Assignment 4 Part 1

The first part of the assessment was provided in the form of a written assignment (Part 1). Part 1 (see Appendix A) provided students with an overview of an open cut coal mine at which a potential wedge failure in the highwall was being monitored using prisms and total stations. The students were also provided with the following information:

- Weather forecast for the previous and current week;
- Yearly rainfall patterns for the mine's geographic location;
- Average coal production rate (t/h);
- Mining equipment that are located within the projected failure zone;
- Average rate of movement for each prism monitoring point over the previous week; and
- A sample Trigger Action Response Plan (TARP) which could be used as a template.

Using the provided information, the students were asked to develop a TARP in their allocated groups to manage the wedge failure ensuring no personnel or equipment loss.

5.1.2.2 Assignment 4 Part 2

The second part of the assignment asked students to use the information provided in Part 1 along with their developed TARP to create a new TARP while going through DSFRM in the ILF at UQ. Students were given one and a half hours to create a new TARP in their groups of four, given the dynamic data provided to them in the simulation through the in-game "Slope Monitoring System".

Due to the size of the ILF allowing for a maximum of 30 students at any time, the class was divided into three groups of 24 which resulted in three VR sessions being run back to back. At the start of each session the students were asked to hand in their completed TARP from Part 1 and were then provided with an introduction to the simulation and a short demonstration of the controls and user interface. Students were then given with an explanation of what they were required to do during the session and how the session was going to run. The gamepad was then handed over to the students and the simulation was started.

Students were allowed to explore the mine site as they pleased and drive a haul truck using "Truck Mode". Students were also made aware that events occurring on the mine site (i.e. the progression of the slope towards failure) would happen regardless of them being present at the location in the virtual environment. A second screen displaying the slope monitoring system (SMS) was provided to students so as to allow them view the SMS while other groups were exploring the mine site.

Five minutes before failure, the students were asked to submit their TARP and observe the failure. Figure 36 and Figure 37 are photographs which were taken during two of the VR sessions.

Figure 36. Students monitoring changes in the rate of movement of the slope
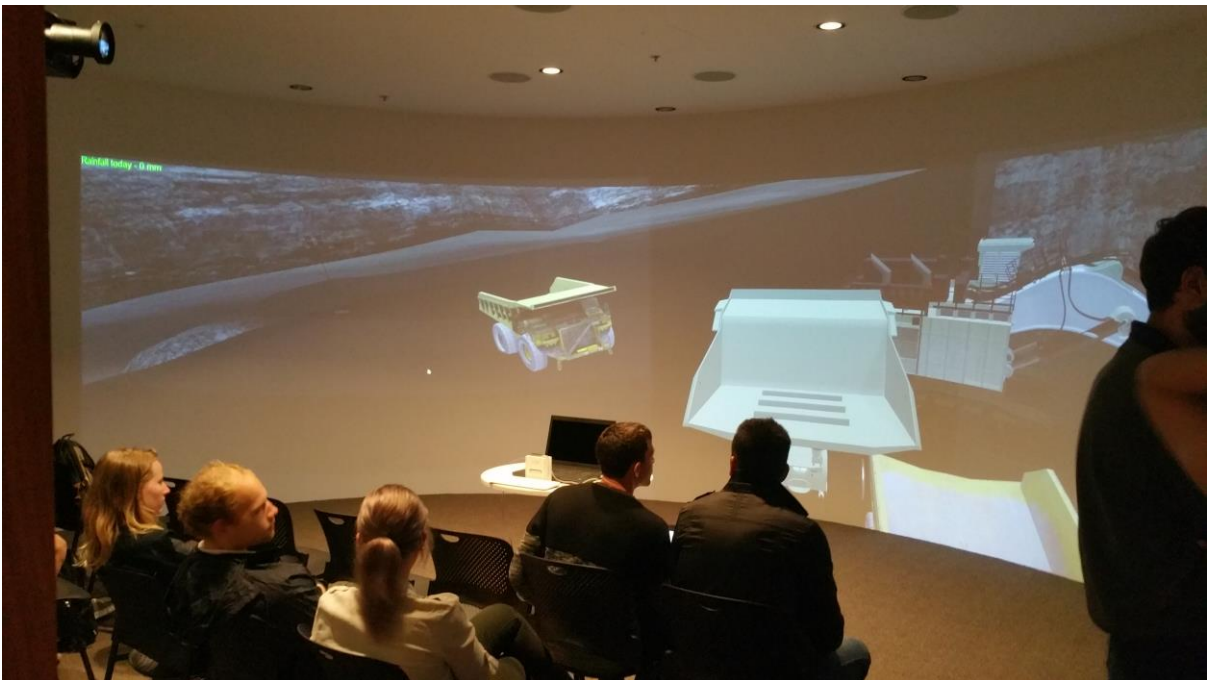
Figure 37. Students driving a truck using "Truck Mode".

5.1.2.3 Assignment 4 Criteria

The assignment was designed to assess the students' ability to develop a TARP that would manage the slope failure risk through the use of monitoring triggers and appropriate trigger levels. Students were expected to adopt the role of the management team at the open cut mine and apply risk management principles to determine appropriate stakeholder responses for each trigger level. It was assumed

that students had a basic understanding of slope failures and the factors which contribute to the failure of a slope as well as the consequences.

As such the assessment criteria for the assignment were centred on the following:
- Identification of key risk variables;
- Identification of appropriate trigger levels;
- Stakeholder identification and actions/responses;
- Degree of completeness (Has the TARP successfully managed the failure with all personnel and equipment removed from the failure zone prior to failure); and
- Equipment removal time before failure.

Trigger Action Response Plans were not a detailed component of the risk management section in MINE4121. This meant that students were required to research what was involved in creating one and the information it was required to contain. Using their researched information, the risk management principles taught in MINE4121 and the provided information in the assignment sheet, students were expected to:
- Identify appropriate risk variables including but not limited to:
  - Rainfall;
  - Rate of movement;
  - Cumulative Slope Displacement; and
  - Physically visible deterioration of the slope.
- Determine appropriate trigger levels for the risk variables identified;
- Identify key stakeholders and their actions including:
  - Mine Manager;
  - Open Cut Examiner;
  - Geotechnical Engineer;
  - Operators;
  - Site Senior Executive;
- Ensure the pit was evacuated and all equipment removed at least 24 hours before the failure occurred.

The slope monitoring system in the VR simulation allowed for students to be provided with a dynamic data set which continually updated and progressed throughout the VR session. Due to the availability of this dynamic data in Part 2 it was decided that the

trigger level criteria would be relaxed for Part 1 to compensate for the lack of data provided using the written medium so as to not disadvantage students. In order to do this, the original trigger level criteria shown in

Table 9 was altered to give the criteria shown in Table 10. The full marking criteria for Part 1 and Part 2 can be found in Appendix A.

TABLE 9.
Initial Trigger levels criteria

Identification of appropriate trigger levels – Have appropriate trigger levels been identified for each risk variable?	*Trigger levels within +/- 25% of target range*	*Trigger levels between +/- 25% and +/- 50% of target range*	*Trigger levels outside of +/- 50% of target range*
	2	1	0

TABLE 10.
Relaxed trigger level criteria

Identification of appropriate trigger levels – Have appropriate trigger levels been identified for each risk variable?	*Trigger levels within +/- 50% of target range*	*Trigger levels between +/- 50% and +/- 100% of target range*	*Trigger levels outside of +/- 100% of target range*
	2	1	0

It was expected that the major difference between Part 1 and Part 2 would only be the trigger levels for each monitoring trigger hence the difference in marking criteria. Based on the information provided in Part 1 and Part 2, it was assumed that all other criteria could be satisfied by students equally well for both parts.

The trigger level limits used for marking the assignments were determined through a back analysis of the prism data set used. The limits were calculated to allow a minimum of 24 hours between evacuation and failure.

5.1.2.4 Post VR Session Survey

An online survey was given to students after they had completed the VR session. The survey comprised of seven multiple choice based on a Likert Scale and 2 open ended questions. The purpose of the survey was to qualitatively determine the influence the VR session had on the students' understanding of how risk management principle are

applied and if the use of VR enhanced their learning experience. The seven questions were designed to address the following aspects:

- Level of engagement/immersion;
- Functionality or added benefit from using the leap motion for hand interaction;
- Visual realism of simulation;
- Ease of use (user interface and controls);
- Perceived benefits of dynamic VR scenario;
- Assessment medium of choice; and
- Perceived increase in understanding of risk management principles and their application.

Figure 38 illustrates the online survey as viewed by students via a web browser.

MINE4121 Virtual Reality Assessment Survey

1. Please indicate how much you agree or disagree with each of the following statements:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found the simulation exercise to be more engaging and immersive as opposed to tradition tutorials in terms of the learning experience.	○	○	○	○	○
The integration of hand interaction via the leap motion enhanced the learning experience by increasing the interactivity of the simulation	○	○	○	○	○
The visual detail of the simulation graphics was very high and realistic.	○	○	○	○	○
I found the user interface and controls easy to use and could easily navigate through the simulation.	○	○	○	○	○
The use of a dynamic scenario where the risk variables change over time is a more effective means of testing the application of risk management principles as opposed the standard assessment method.	○	○	○	○	○
If given a choice, I would prefer a VR assessment over a traditional assessment.	○	○	○	○	○
My understanding of how to apply risk management principles has been further developed through this exercise	○	○	○	○	○

2. Any other comments or suggestions regarding the VR session?

3. What other mining or mining related scenarios would you like to see in VR?

Done

Figure 38. Post-VR Online survey

The survey was opened to students directly after the completion for the VR session and remained open until the 6th of November 2015.

5.1.3   *Corinda State High School Pre & Post VR Session Quiz*

A high school senior Earth Sciences class from Corinda State High School was taken through a VR session on Thursday August 20th as part of a visit to UQ. The class was comprised of eighteen grade twelve and five grade eleven students who had recently completed an assignment which required them to research open cut and underground mining methods.

The visit by the high school class presented the opportunity to collect supplementary data for the project. Permission was sought to allow the students to be part of a small observational study which was granted. A simple quiz was developed focussing on mining systems and associated mining equipment (see Appendix DC).

Prior to the VR session the quiz was completed by the students to assess their existing knowledge of mining systems and equipment gained from the completion of their assignment. The VR session included a virtual visit to both a longwall underground mine and an open cut coal mine. Various mining equipment and their role in their associated mining systems were inspected in VR and discussed. At the end of the session a fresh copy of the VR session quiz was provided to the students to complete once again.

Both sets of quizzes were marked and their data sets were then statistically analysed using a paired t-test to determine if there was a significant difference in the class' mean results after the VR session.

6.   DATA ANALYSIS AND RESEARCH FINDINGS

6.1   STATISTICAL ANALYSIS – PAIRED T-TEST

The statistical analysis tool, Minitab, was used to analyse the data collected from the paired-data observational study. This statistical analysis method was chosen based on the data collection method. As there were two measurements taken for each group i.e. the assessment results for Part 1 and Part 2, the samples were considered dependant (Runkel, 2013). This meant the paired t-test would be most appropriate as it is used when you have two related observations (i.e. two observations per subject) and you want to see if the means on these two normally distributed interval variables differ from one another (i.e. both data sets need to be normally distributed) (Shier, 2004).

6.1.1   MINE4121 Assignment 4

The results of the two assessments are shown in Table 11.

TABLE 11.
Assignment 4 results

Group	Part 1	Part 2	Delta
1	60%	80%	**20%**
2	70%	80%	**10%**
3	90%	90%	**0%**
4	70%	80%	**10%**
5	70%	80%	**10%**
6	50%	70%	**20%**
7	90%	90%	**0%**
8	40%	80%	**40%**
9	70%	80%	**10%**
10	70%	70%	**0%**
11	40%	70%	**30%**
12	60%	90%	**30%**
13	60%	60%	**0%**
14	60%	60%	**0%**
15	80%	100%	**20%**

16	20%	60%	**40%**
17	30%	70%	**40%**
18	40%	90%	**50%**
19	50%	80%	**30%**

For the 19 groups who completed the assignment it can be seen that the increase in assessment results range from 0% to a maximum of 50%. No negative difference was observed.

For Part 1: Min = 20%, Max = 90%

Max - Min = 70%

For Part 2: Min = 60%, Max = 100%

Max – Min = 40%

The Ryan-Joiner (RJ) test for normality was conducted on both data sets to ensure they fit a normal distribution. This is a prerequisite for the paired t-test. Figure 39 and Figure 40 show the Minitab output for the RJ tests. The correlation factors for each test are significantly close to 1 and can therefore be deemed normal.
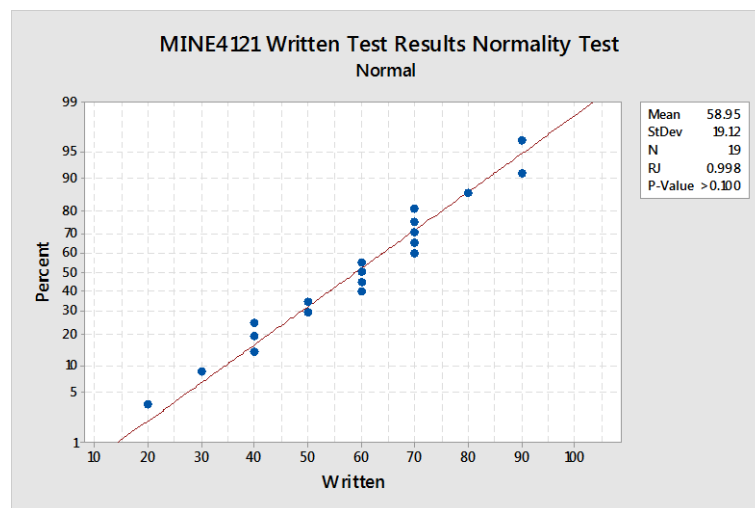

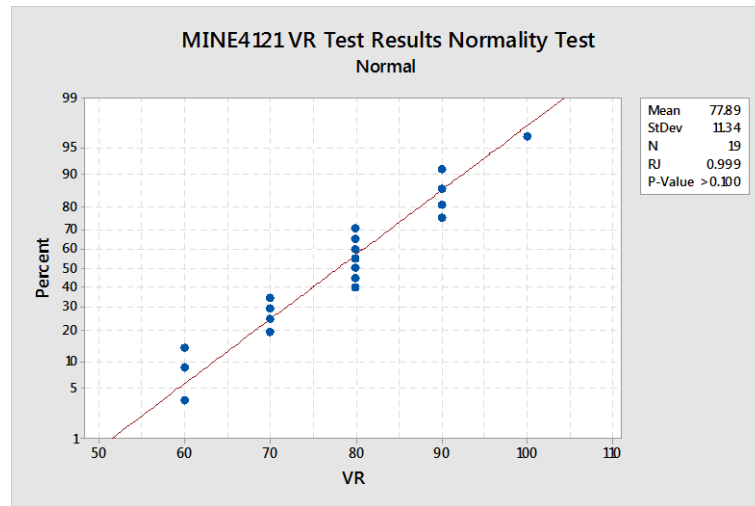Figure 39. Part 1 RJ test for normality

Figure 40. Part 2 RJ test for normality

A paired t-test was then carried out. The output from Minitab is shown below:

MINE4121 Percentage Scores Paired T-Test and CI: VR, Written

```
Paired T for VR - Written


              N    Mean   StDev   SE Mean
VR           19   77.89   11.34      2.60
Written      19   58.95   19.12      4.39
Difference   19   18.95   16.29      3.74



95% CI for mean difference: (11.09, 26.80)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 5.07   P-Value = 0.000
```

From the Minitab output it can be seen that the P-value is less than 0.05 which indicates that the mean absolute difference in the assessment results between Part 2 (VR) and Part 1 (written) of 18.95% can be considered statistically significant. This means that the average group assessment mark was ~19% greater for the VR based assessment (Part 2) than the written assessment (Part 1) which provides strong evidence for the benefits of VR-aided teaching. The relative increase in results from after the use of the VR simulation can be calculated as follows:

$$\frac{\mu_{P2} - \mu_{P1}}{\mu_{P1}} * 100 = \frac{18.95}{58.95} * 100 = \mathbf{32.1}\%$$

Where:

μ_{P1} = Part 1 mean

μ_{P2} = Part 2 mean

This indicates a 32% relative increase in student results was achieved by providing students with a VR simulation based version of the initial written assignment (Part 1).

6.1.2   Corinda State High School Quiz

The results from the CSHS pre and post-VR quiz were analysed using the same method as for the Assignment 4 result. Figure 41 and Figure 42 show the Minitab output for the RJ tests. The correlation factors for each tested data set are significantly close to 1 and can therefore be deemed normal.
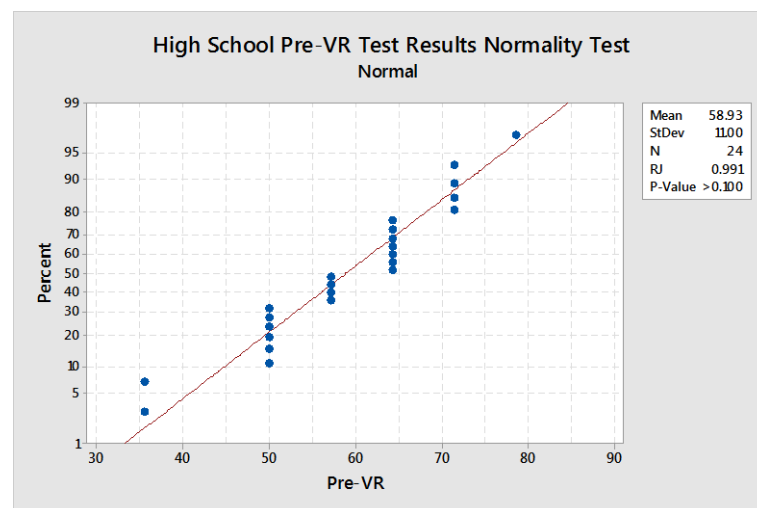

Figure 41. High School Pre-VR RJ test for normality.
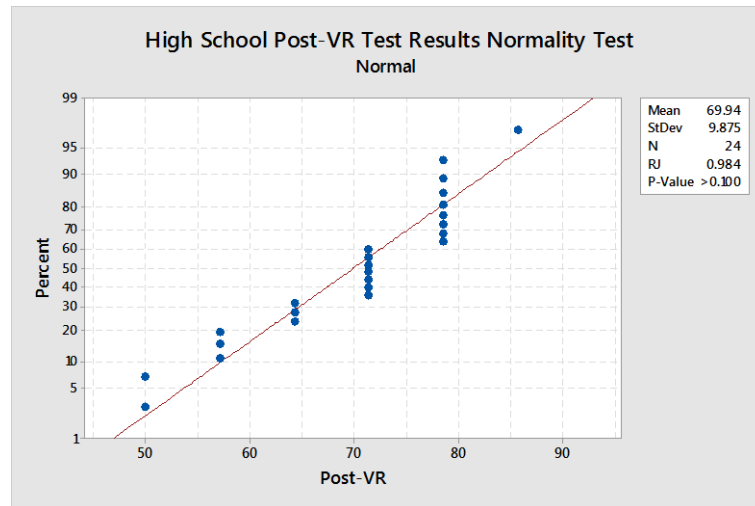
Figure 42. High School Post-VR RJ test for normality.

The output from the paired t-test carried out in Minitab is shown below:

High School Percentage Scores Paired T-Test and CI: Post-VR, Pre-VR

```
Paired T for Post-VR - Pre-VR


              N    Mean   StDev   SE Mean
Post-VR      24   69.94    9.87      2.02
Pre-VR       24   58.93   11.00      2.24
Difference   24   11.01   14.74      3.01



95% CI for mean difference: (4.79, 17.24)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 3.66  P-Value = 0.001
```

From the Minitab output it can be seen that the P-value is less than 0.05 which indicates that the mean difference in the quiz scores between the pre-VR quiz and post-VR quiz of 11.01% can be considered statistically significant. The relative increase in results from pre-VR to post-VR can be calculated as follows:

$$\frac{\mu_{Post} - \mu_{Pre}}{\mu_{Pre}} * 100 = \frac{11.01}{58.93} * 100 = \mathbf{18.6\%}$$

Where:

μ_{Post} = Post-VR mean

μ_{Pre} = Pre-VR mean

This indicates that the average quiz score increased by 18.6% after students were taken through the VR mining simulations in the ILF.

6.2   RESEARCH FINDINGS

From the analysis of both the CSHS and MINE4121 studies, it was found that a statistically significant increase in the mean assessment result was achieved after the VR session was completed. The use of the VR simulation can therefore be seen to provide an increased benefit for student learning in mining education based on the results of the study conducted.

While it can be argued that the increase achieved in the MINE4121 observational study was a direct result of the lack of data provided to students in Part 1, it should be noted that the ability to provide the required data dynamically is a benefit of the VR medium. If the slope stability data for part or most of the week (in-game) was provided to students in Part 1, they would have been able to plot inverse velocity and predict an estimated time of failure for the wedge. This defeats the purpose of applying risk management fundamentals to manage the risk by identifying monitoring triggers and appropriate triggers levels for those triggers. The VR medium allowed for the data to be presented dynamically (i.e. changing over time) over the duration of the VR session during which the students could determine appropriate trigger levels by taking into account all contributing factors (rainfall, cumulative slope displacement, rate of movement, etc) which were presented in the VR simulation. This would not be possible in the standard written medium as all the data would need to be provided at the outset of the assignment which is not a true representation of real life events.

The CSHS quiz results for a sample of 24 students showed an absolute mean difference of ~11% which was calculated as relative increase of ~18%. This shows that an increase in the students' knowledge of mining equipment and systems was achieved after the VR session was complete. Due to students not having written their names on either of the quizzes, it was not possible to determine if any one scored lower on the post-VR quiz than on the pre-VR quiz.

It can be argued that the students could have been presented with the same information in a lesson-type format which would have resulted in a greater retention of the information. That would have meant students would be instructed and taught the information. The VR session was approached as a virtual tour of two mine sites during which students were allowed to construct their own understanding of the mines and the equipment viewed.

7. SURVEY RESULTS AND DISCUSSION

7.1 POST-VR SURVEY RESULTS

A total of 64 students undertook the survey during the seven weeks that it was available. This can be calculated as an 84% response rate. Table 12 shows the results from the online survey.

TABLE 12.
Post-VR session survey results.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total	Weighted Average
I found the simulation exercise to be more engaging and immersive as opposed to tradition tutorials in terms of the learning experience.	12.50%	6.25%	14.06%	51.56%	15.63%		
	8	4	9	33	10	64	3.52
The integration of hand interaction via the Leap Motion enhanced the learning experience by increasing the interactivity of the simulation	15.63%	9.38%	26.56%	35.94%	12.50%		
	10	6	17	23	8	64	3.20
The visual detail of the simulation graphics was very high and realistic	7.94%	15.87%	9.52%	50.79%	15.87%		
	5	10	6	32	10	63	3.51
I found the user interface and controls easy to use and could easily navigate through the simulation.	9.52%	4.76%	17.46%	50.79%	17.46%		
	6	3	11	32	11	63	3.62
The use of a dynamic scenario where the risk variables change over time is a more effective means of testing the application of risk management principles as opposed the standard assessment method.	11.11%	6.35%	9.52%	52.38%	20.63%		
	7	4	6	33	13	63	3.65
If given a choice, I would prefer a VR assessment over a traditional assessment.	15.87%	6.35%	12.70%	42.86%	22.22%		
	10	4	8	27	14	63	3.49

My understanding of how to apply risk management principles has been further developed through this exercise	17.46%	1.59%	19.05%	42.86%	19.05%		
	11	1	12	27	12	63	3.44

From the multiple choice question results it is evident that the majority of students were engaged in the session and found it to be useful. Table 13**Error! Reference source not found.** provides a summary of the basic statistics from the post-VR survey.

TABLE 13.
Post-VR survey basic statistics.

Survey Question	Minimum	Maximum	Median	Mean	Standard Deviation	Percentage of respondents that agreed or strongly agreed
Q1.1	1.00	5.00	4.00	3.52	1.20	67.19
Q1.2	1.00	5.00	3.00	3.20	1.24	48.44
Q1.3	1.00	5.00	4.00	3.51	1.17	66.66
Q1.4	1.00	5.00	4.00	3.62	1.12	68.25
Q1.5	1.00	5.00	4.00	3.65	1.20	73.01
Q1.6	1.00	5.00	4.00	3.49	1.33	65.08
Q1.7	1.00	5.00	4.00	3.44	1.31	61.91

It can be seen that for 6/7 questions the number of students that agreed or strongly agreed with the statement was greater than sixty percent. The responses to the question regarding the integration and functionality of the Leap motion for hand interaction shows that less than 50% of the class found this to be useful in terms of their learning experience. This indicates that the Leap Motion did not enhance the interactivity of the simulation as intended.

The two open ended questions allowed students to provide additional feedback or voice concerns regarding the VR session (how it was run, assignment requirements, etc – Q2) and provide examples of other mining related scenarios they would like to see in VR (Q3).

Responses to Q2 were classified as shown in Table 14.

TABLE 14.
Post-VR Survey Q2 comment classification

Comment Type	Number of Comments
Positive	2
Negative	5
Positive/Constructive	2
Negative/Constructive	2
Constructive	12
Null	2
Total	**25**

From Table 14 it can be seen that the positive, positive constructive and constructive comments make up 64% (i.e. 16/25) of the comments received. Constructive comments provide an idea to improve any subsequent sessions without major indication of positive or negative experience. Comments involving motion sickness are included as negative. Null comments are for students who left a null response such as "N/A".

For Q3 there were 32 responses providing an indication of a mining or mining related concept they would like to see in VR. The responses are summarised according to the type of scenario suggested by the respondents:

- Underground/open cut mining systems and operations – 13
- Drill and Blasting scenario – 5
- Underground roof failure/ ground support failure – 3
- Traffic incidents due to light-heavy vehicle interaction – 1
- Mine rescue and emergency response – 5
- Unclassified – 3
- Null – 2

A complete list of responses for Q2 and Q3 can be found in Appendix D.

7.2   SURVEY RESULTS DISCUSSION

7.2.1   Question 1 (Likert Scale Multiple choice)

From the survey responses to the Likert scale questions it was found that:

- Greater than 65% of students indicated they:
  - found the VR session more engaging than the written assessment in terms of the learning experience; and
  - found the visual detail of the simulation to be high and realistic.
- Less than 50% of students found the inclusion of the Leap Motion for hand interaction useful. The intention was for the hand interaction to be a key factor in enhancing the immersive experience for students however this was not the case. It was found that the lack of experience with the Leap Motion resulted in the students not being able to properly use the hand interaction and produced a bit of frustration which then resulted in a decreased sense of immersion and engagement with the simulation. The use of the hand functions was barely used in all three sessions. Recent updates to the Leap motion software have greatly increased the accuracy of tracking and usability of the system. In order to get students to use the Leap Motion effectively during the sessions, they would need to be allowed to run through a tutorial on how to use it individually prior to the session so they understand how it works and have some practice with using it.
- Most students who attempted to navigate through the simulation were successful. It was observed that students found it easy to navigate through the simulation and switch between modes. This is reflected in the survey responses were 68% of respondents agreed or strongly agreed with the statement. There was some feedback regarding the controls for "Truck Mode" which were not as user friendly for regular gamers who are accustom to a specific configuration that is shared by most console racing games (e.g. Gran Turismo, Need for Speed).
- Greater than 70% of students indicated that they found the use of the VR session as a more effective means of testing the application of risk management principles as opposed to the written assignment in Part 1.
- Greater than 60% indicated they would prefer the VR assignment over the written assignment and felt they had further developed they're understanding of risk management principles.

7.2.2   Question 2

Suggestions from the survey responses and discussions with others who have tried the simulation indicate that more instruction needs to be provided throughout the simulation and secondary objectives need to be included to engage the user while monitoring the slope. The inclusion of an inverse velocity plot that updates as the slope deforms would also be more aligned with industry practice. This indicates there is still a reasonable amount of work that is required to bring the simulation up to the standard required to completely immerse and engage students in the learning process.

One way to address this would be to alter the simulation design to have an array of objectives that need to be completed while monitoring the slope progression. The user may attempt any of the objectives whenever they please however they may require knowledge or skills gained from the completion of other objectives to complete the task they are attempting. Should they fail to complete the objective; they will then be prompted to complete the prerequisite objective/task to gain the knowledge or skill required to complete the objective. This would allow the user to remain engaged with simulation while completing the required objectives. This would also require the session to be longer and be structured so that each group gets to use the simulation independently.

7.2.3   Question 3

From the responses was evident that students saw a benefit in the use of a VR simulation to teach mining concepts and theory. Majority of the responses received indicate that students would like see mining systems explained in a virtual environment. The use of mining simulations to teach the 3rd year course "Mining Systems" (UQ course code: MINE3122) was suggested by numerous students via verbal communication after the VR session. This would allow students to get a visual understanding of the various equipment and operations that are on a mine site as well as a systems overview of the mining system being taught.

7.3   TUTOR FEEDBACK

In order to gain a third-party perspective on the VR sessions, feedback was obtained from the tutor, Mr. Isaac Dzakpta, who attended the first VR session. The following written feedback was provided by Mr. Dzakpta who was provided with the sub-headings below and asked to write a paragraph for each detailing his observation.

Overall observation:

In my assessment, the use of VR in teaching for implementing the TARP exercise helped in making the teaching/learning process more interesting and pleasant to the students, facilitating the tutor's ability to explain the subject matter as the student interacted with the virtual "risk element". The VR approach presented an opportunity for the students to learn within a perceived real situation, enhancing the visualization and the interaction sensation with the learning object. Specific comments on relevant areas are as follows:

- Level of engagement/immersion:

In the particular session that was observed, nearly half of the group did not physically interact with the tools but were keenly intrigued by the sensation of the being placed within the virtual working face and putting into the right size perspective, what the consequences could be if inadequate responses were made with respect to the hazards and risks identified.

- Visual realism of simulation:

In my opinion, since the consequence/outcomes was predetermined it did not afford the student the opportunity to explore various response plans and likely consequence in those scenario, coupled with the fact that student had already performed a written version of the TARP. The tutor did clarify that due to time constrains, only one option could be completed before the trial.

- Ease of use (user interface)

It was observed that those students who appeared to have an affinity for virtual game tools were however deeply engrossed in using the VR interaction tools. The

approached seem to presume that users were already familiar with the VR control tools, which was the case.

- Assessment medium of choice (written or VR)

From my personal observation, a combination of the two medium would have better outcomes for the learner. I would propose that the VR session preceded the written format as it provided the immersion experience and make the appreciation of the risks more real right from the onset.

8.   CONCLUSIONS

The aim of this project was to determine the increase in student assessment results when presented with a scenario-based assignment using a VR simulation as opposed to the traditional written format. The objectives were to:

- To develop a VR mining simulation using the five roles of a student in a constructivist learning environment as a framework;
- To conduct a paired-data observational study using the developed simulation with fourth-year mining undergraduate students; and
- To use the results from the paired-data observational study to provide a quantification of the benefits of using a VR simulation as the medium of presentation for scenario-based assignments in mining education.

These objectives were achieved by:

- The development of an open cut coal mine simulation based around a slope monitoring scenario;
- The use of the simulation and a developed assignment to design and conduct a paired-data observational study which provided data which was then analysed; and
- The analysis of the collected data from the paired-data observational study conducted with 4th undergraduate mining students finding that the use of a VR simulation to present an assignment resulted in a ~32% relative increase in assessment results when compared to the traditional written format. A smaller study of the same nature conducted with high school students also found an 18.6% relative increase in quiz scores after the VR simulation was demonstrated.

From the results of the two studies conducted it can be concluded that the use of a VR simulation in mining education has a positive effect on student assessment results and can produce a significant benefit when used for scenario-based learning objectives. This can be quantified as a relative increase of between 18 and 32% in student assessment results, or an average of 25%. This should be regarded as an upper limit of learning benefits given that it was not possible to organise an experimental control

group due to fear of disadvantaging students and time restrictions due to the course assessment schedule.

9.   RECOMMENDATIONS

Further research is required to test the benefits achieved by the use of full immersion through HMDs as these systems could be cheaper to setup in the near future as oppose to the standard 180/360 degree curved screens. With the Oculus Rift and VR-Ready PC bundles on pre-order currently from ~A$2,500 (Oculus VR, 2016), setting up a VR lab with 20-30 of these as "VR-stations" could easily be seen as more cost effective at A$50,000 to A$75,000 as opposed to large-screen visualisation systems which cost A$300,000 to A$500,000.

Group interaction would occur in this setting through the use of avatars controlled by students from a 'first person view' in a multiplayer networked simulation. The educator would join students in the VE and teach a location based lesson in the VE which would allow for concepts to be demonstrated using 3D models of real-life objects and/or animations of processes in VR.

Research into simulation design techniques that focus on reduced cognitive load could also be an area of interest which could lead to the development of simulations that more efficiently train personnel by providing visual cues in the simulation to help the user more effectively construct knowledge from the information being provided to them.

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APPENDIX A

THE UNIVERSITY
OF QUEENSLAND
AUSTRALIA

Name: ………………………

Student No. ………………..

ENGG 4121 Mine Management

Assignment 4 - Slope Failure Risk Management Part 1

Your group is part of the management team at an open coal mine (Figure 1) in the Hunter Valley, New South Wales (near Singleton). The scenario is set during the month of February over a period of 7 days.

Mine Details:
- Mining method: Truck & shovel
- Average Production Rate (Coal): 2000 t/h
- End of Month Production Target: 0.4 Mt
- February total production to date: 0.27 Mt

Figure 1. Satellite view of Open Cut Coal Mine.

Slope monitoring scenario:

A geotechnical assessment of the highwall found two major persistent discontinuities intersecting resulting in a significant risk of a wedge failure. The failure zone is being monitored using 5 prisms at the locations (shown in Figure 2) whose rate of movement over time is tracked by total stations. The average rate of movement of each prism for the past week is shown in Table 1.

TABLE 1.
Average rates of movement for previous week

Prism Monitoring Point	Average rates of movement (mm/h)
1	0.011
2	0.020
3	0.015
4	0.014
5	0.013

Below the projected failure zone is a coal mining operation which is working on coal production. The coal mining fleet consists of:

- 5 x Cat 793F
- 1 x Liebherr R9800 Hydraulic Excavator
- 1 x Cat 844k Wheel Dozer
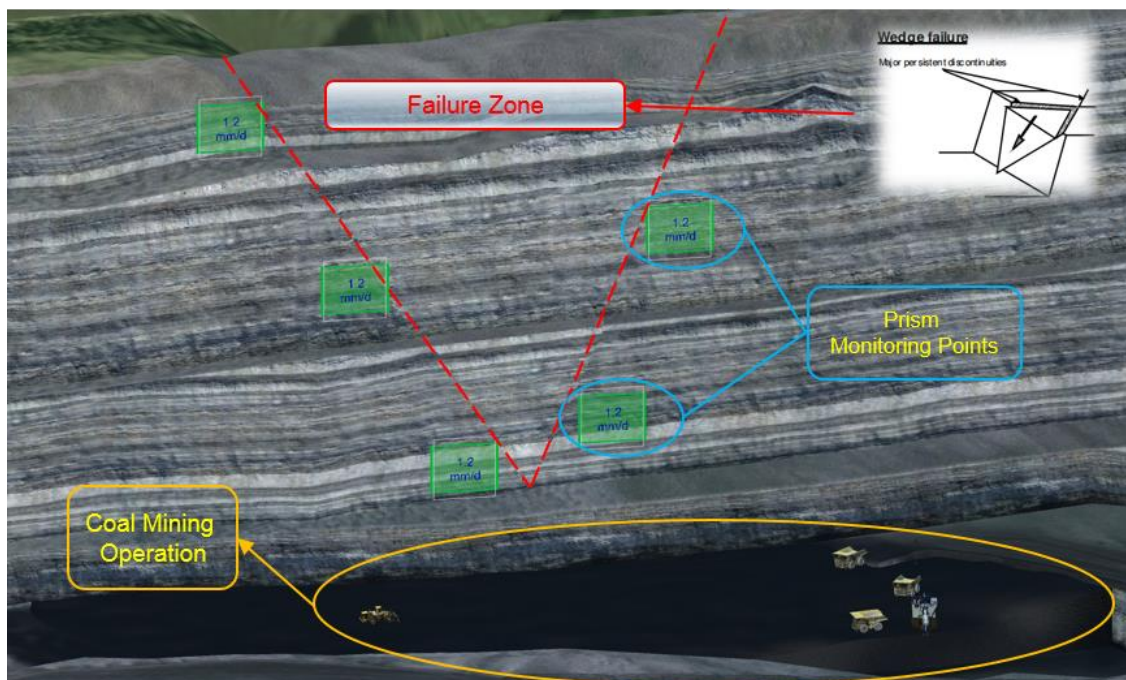
Figure 2. Projected Failure Zone

It is the last week of the month and production is behind schedule, therefore coal production is of utmost importance in order to reach production targets for the month. There are no blasts scheduled for the rest of the month.

Based on the scenario and additional information provided; you and your team are required to assess the scenario and develop a Trigger Action Response Plan (TARP) to manage the risk posed by the potential geotechnical wedge failure being monitored. Your TARP should aim to maximize production while minimizing the risk of equipment loss.

Additional Information:
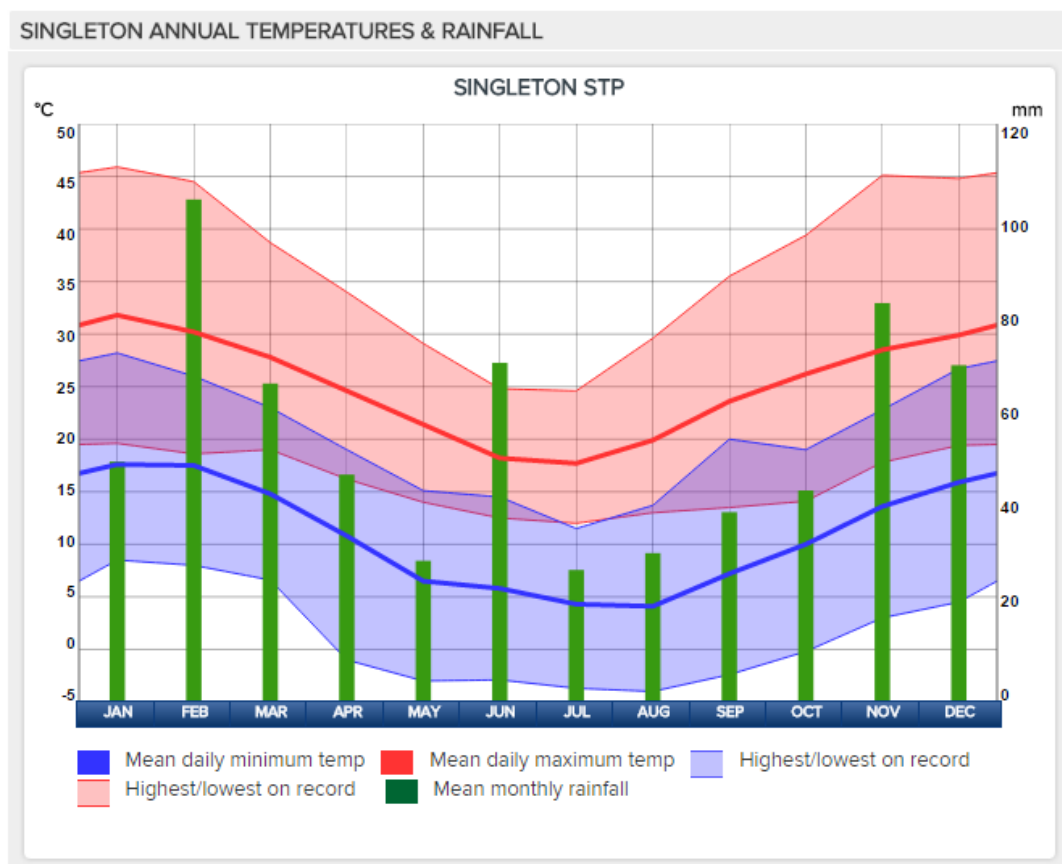
Figure 3. Singleton Average Monthly Temperatures and Rainfall (Weatherzone.com.au, 2015)

Weather forecast for the previous week:

Singleton Weather							
	Mon	Tue	Wed	Thurs	Fri	Sat	Sun
Summary	Sunny	Sunny	Cloudy	Cloudy	Possible shower	Increasing sunshine	Increasing sunshine
Max Temp (∘C)	28	27	30	31	28	29	29
Min Temp (∘C)	15	16	16	17	14	16	18
Chance of Rain	5%	5%	20%	5%	25%	10%	5%
Rain Amount	<1 mm	<1 mm	<1 mm	<1 mm	<5mm	<1 mm	<1 mm

Weather forecast for the coming week:

Singleton Weather							
	Mon	Tue	Wed	Thurs	Fri	Sat	Sun
Summary	Sunny	Sunny	Possible shower	Showers	Showers	Increasing sunshine	Increasing sunshine
Max Temp (∘C)	28	28	29	29	28	29	30
Min Temp (∘C)	15	16	16	17	14	16	18
Chance of Rain	5%	5%	20%	90%	70%	10%	5%
Rain Amount	<1 mm	<1 mm	<5mm	30-50 mm	20-30 mm	<1 mm	<1 mm

Assessment Criteria- Slope Failure TARP P1 (written)

Criteria	Good	Satisfactory	Unsatisfactory
Identification of Key Risk Variables – Have all of the key risk variables been identified and clearly stated?	All key risk variable identifies	Key risks missing 1 or 2 variables	Key risks missing 3 or more variables
	2	1	0
Identification of appropriate trigger levels – Have appropriate trigger levels been identified for each risk variable?	Trigger levels within +/- 25% of target range	Trigger levels between +/- 25% and +/- 50% of target range	Trigger levels outside of +/- 50% of target range
	2	1	0
Stakeholder identification and actions/response – Have the key stakeholders been identified with an appropriate response/action for each trigger level?	All key stakeholders identified	Missing 1 or 2 key stakeholders	Missing 3 or more key stakeholders
	2	1	0
Degree of completeness – Does the TARP successfully manage the wedge failure with no equipment loss and maximize production leading up to the failure event?	Yes- Success	n.a.	No - Failure
	2	1	0
Equipment removal time before failure i.e. all equipment removed from pit and all personnel evacuated	72 > t > 24 hours	>72 hours or 24 > t > 0 hours	Equipment lost
	2	1	0

1. Identification of key risk variables – (2 marks)
2. Identification of appropriate trigger levels (2 marks)
3. Stakeholder identification and actions/responses (2 marks)
4. Degree of completeness (2 marks)
5. Equipment removal time before failure (2 marks)

Marked total = _/10 * 6.5

THE UNIVERSITY
OF QUEENSLAND
AUSTRALIA

Name: ………………………
Student No. ………………..

ENGG 4121 Mine Management

Assignment 4 - Slope Failure Risk Management Part 2

Once again you and your group are the management team at an open coal mine in the Hunter Valley, New South Wales (near Singleton). The scenario is set during the month of February over a period of 7 days.

The scenario details remain the same as Part 1 however, your team will now be required to create a new TARP in a virtual reality dynamic risk environment (DSFRM). Refer to the attached User Guide for details on the simulation that will be used in this exercise.

Once your new TARP has been developed and tested in the simulation you are required to state which TARP best managed the slope failure and why.

Assessment Critera- Slope Failure TARP Development P2 (VR)

Criteria	*Good*	*Satisfactory*	*Unsatisfactory*
Identification of Key Risk Variables – Have all of the key risk variables been identified and clearly stated?	All key risk variable identifies	Key risks missing 1 or 2 variables	Key risks missing 3 or more variables
	2	1	0
Identification of appropriate trigger levels – Have appropriate trigger levels been identified for each risk variable?	Trigger levels within +/- 50% of target range	Trigger levels between +/- 50% and +/- 100% of target range	Trigger levels outside of +/- 100% of target range
	2	1	0
Stakeholder identification and actions/response – Have the key stakeholders been identified with an appropriate response/action for each trigger level?	All key stakeholders identified	Missing 1 or 2 key stakeholders	Missing 3 or more key stakeholders
	2	1	0
Degree of completeness – Does the TARP successfully manage the wedge failure with no equipment loss and maximize production leading up to the failure event?	Yes- Success	n.a.	No - Failure
	2	1	0
Equipment removal time before failure i.e. all equipment removed from pit and all personnel evacuated	72 > t > 24 hours	>72 hours or 24 > t > 0 hours	Equipment lost
	2	1	0

- Identification of key risk variables – (2 marks)
- Identification of appropriate trigger levels (2 marks)
- Stakeholder identification and actions/responses (2 marks)
- Degree of completeness (2 marks)
- Equipment removal time before failure (2 marks)

Marked total = _ /10 * 6.5

Assessment Criteria TARP Difference Justification

Criteria	Good	Satisfactory	Unsatisfactory
TARP difference justification – Has the group identified the most effective version of their TARP and justified the differences?	Yes	To some extent	No
	2	1	0

Marked total = _ /2
Assessment Total = TARP P1 + TARP P2 + Difference Justification = _ / 15

APPENDIX B

Dynamic Slope Failure Risk Management (DSFRM) Simulation User Information

DSFRM has been developed as an educational tool for teaching dynamic risk management through the use of a time-scaled, dynamic risk management scenario. DSFRM runs for 7 days which is compressed into a 1.5 hour session using a time-scale of 112, i.e. 1 hour in-game = 112 hours in real life.

The simulation is set in an open cut (truck and shovel) coal mine in the Hunter Valley, NSW during the last week of February. A geotechnical assessment of the highwall has found two major persistent discontinuities which are intersecting resulting in the risk of a wedge failure. As a result, a prism monitoring system consisting of 5 prism points has been installed to monitor the total displacement and rate of movement of the wedge. Operating directly below the projected failure zone is a coal mining fleet which is working on coal production. The mine is behind schedule on coal production due to unforeseen maintenance delays earlier in the month, therefore production is of high importance in order to reach the monthly production target.

It should be noted that while the simulation weather and slope displacement change over time, the mining equipment remain static (unanimated) i.e. the mining operation is not simulated.

User Information

Start Screen

The simulation begins at 06:00 on Monday, outside the crib room near the processing plant and workshop. As the simulation is "Open World", the user is free to go anywhere on the virtual mine site at any time. This means that events occurring on site will happen regardless of the user being present in that location or not.
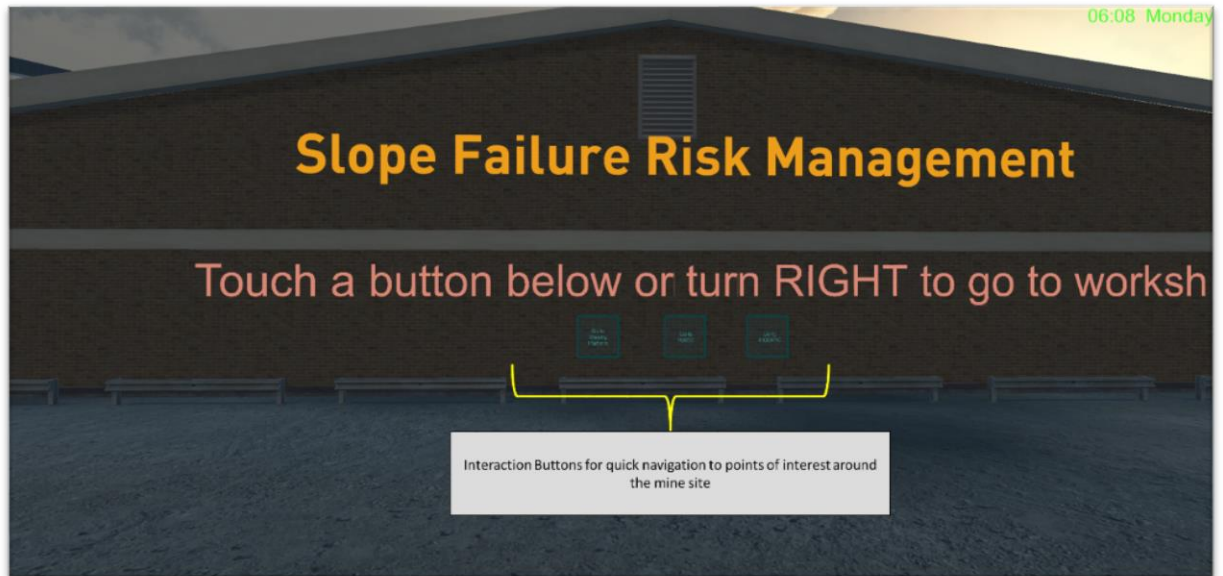
Figure 1. Start Screen

Navigation

Navigation through the virtual mine site is done using an Xbox 360 controller or mouse and keyboard. They can be used separately or in combination as per the user's requirements.

Xbox Controller Input

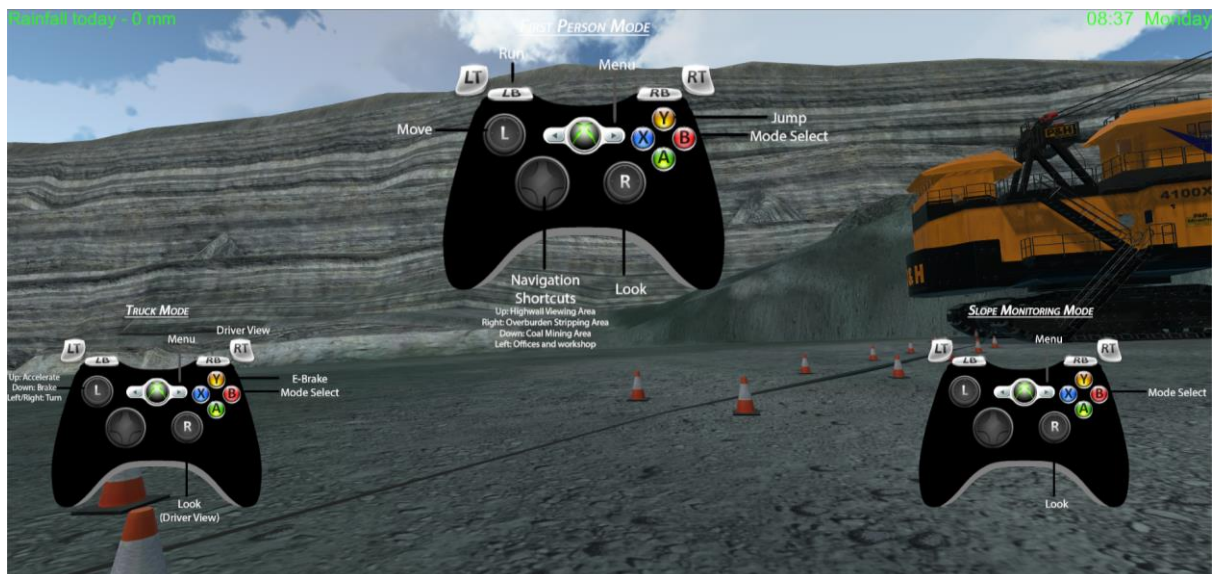The controller layout is shown in Figure 2.

Figure 2. XBox controller layout for each mode.

Keyboard and Mouse input:

The commands for mouse and keyboard input are provided in Table 1.

Table 1. Mouse and Keyboard Commands

COMMAND	INPUT
LOOK (UP, DOWN, LEFT , RIGHT)	mouse movement
MOVE: • FORWARD • BACK • LEFT (STRAFE) • RIGHT (STRAFE)	W S A D
CHANGE HAND MODEL	H
SWITCH/CHANGE MODE	T
PLAY WEDGE FAILURE ANIMATION (UNAVAILABLE DURING ASSESSMENT)	E
RESET WEDGE	R
KEYBOARD SHORTCUTS • SLOPE VIEWING PLATFORM • WASTE REMOVAL AREA (4100XPC) • COAL MINING AREA (R9800) • OFFICE AREA	 1 2 3 4
SWITCH VIEW (TRUCK MODE ONLY)	P
IN-GAME MENU	Esc

Menus

The in-game menu (Figure 3) is toggled on/off by pressing the "Esc" key on the keyboard or "Start" on the Xbox controller. The selection of options within the menu is done using the mouse. This menu has options for

- View the user controls (gamepad and mouse+keyboard);
- Viewing the weather forecast for the previous and current week;
- Changing the timescale;
- Returning to the simulation; and
- Exiting the simulation.

Figure 3. In-game menu.

Features

First-person Mode

First-person mode allows the user to navigate through the mine site from a first-person perspective. In addition to this the user can use their hands to interact with scrollboards and toggle buttons around the mine site. This made possible through the use of a Leap Motion Controller (Figure 4). The scrollboards (Figure 5) provide the user with information regarding risk management or slope failures depending on its location. The toggle buttons (Figure 6) are used to call an action or navigate to ("jump to") other points of interest around the mine site.
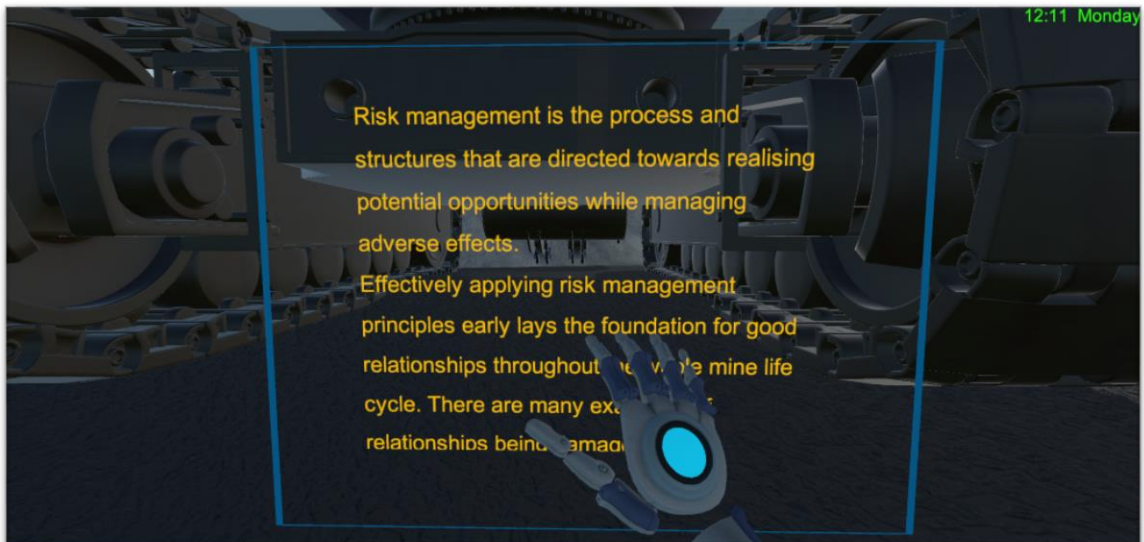

Figure 4. Leap Motion Controller
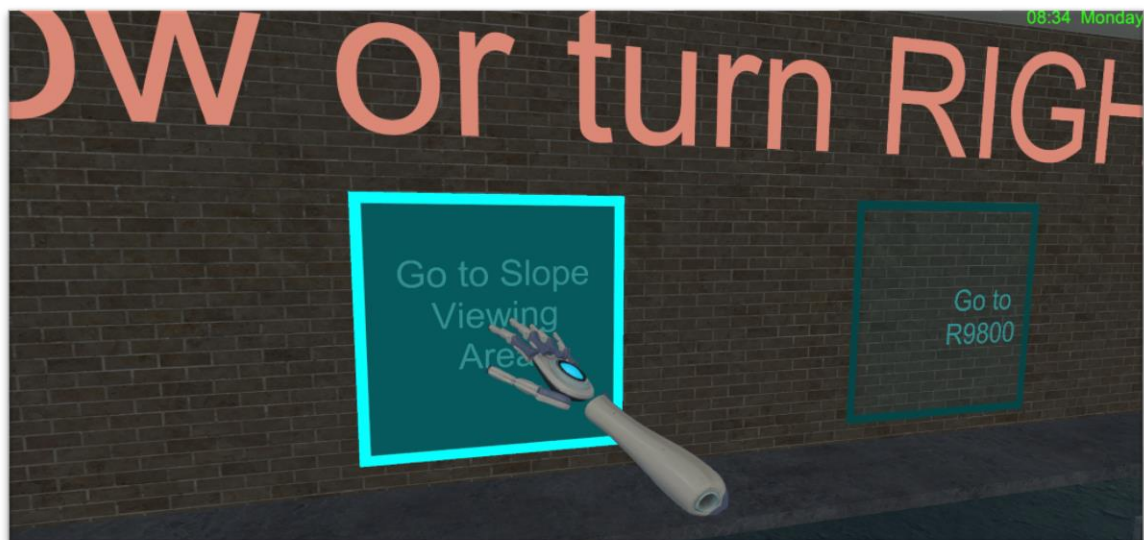
Figure 5. Interactive scrollboards.

Figure 6. Quick navigation interaction buttons.

The use of the Leap Motion controller allows the simulation to use "tool tracking" which enables the user to use a "tool" (e.g. pen or chopstick) which the Leap motion controller tracks and replaces with a predefine object. A torch is used in this simulation as shown in Figure 7.
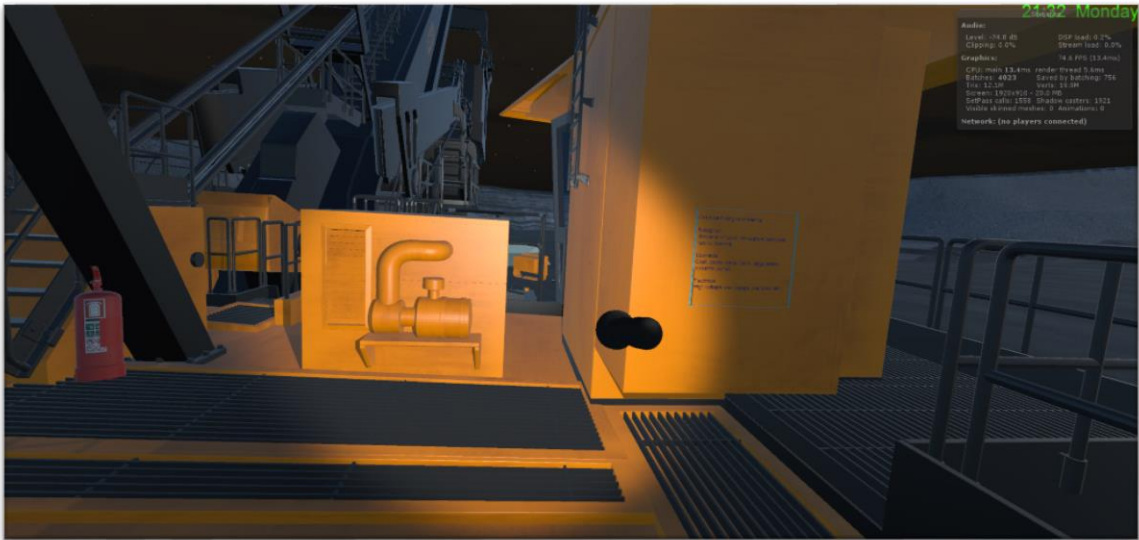
Figure 7. Tool tracking using the Leap Motion Controller

Truck Mode

Truck Mode allows the user to drive a T282c haul truck. Two views are available in this mode:

- Third person aerial view (Figure 8) shows an aerial view of the truck haul;
- Driver View (Figure 9) gives the user a first person view from the driver's seat allowing them to look around the operator's cabin and gain an understanding of the field of view the truck driver has.
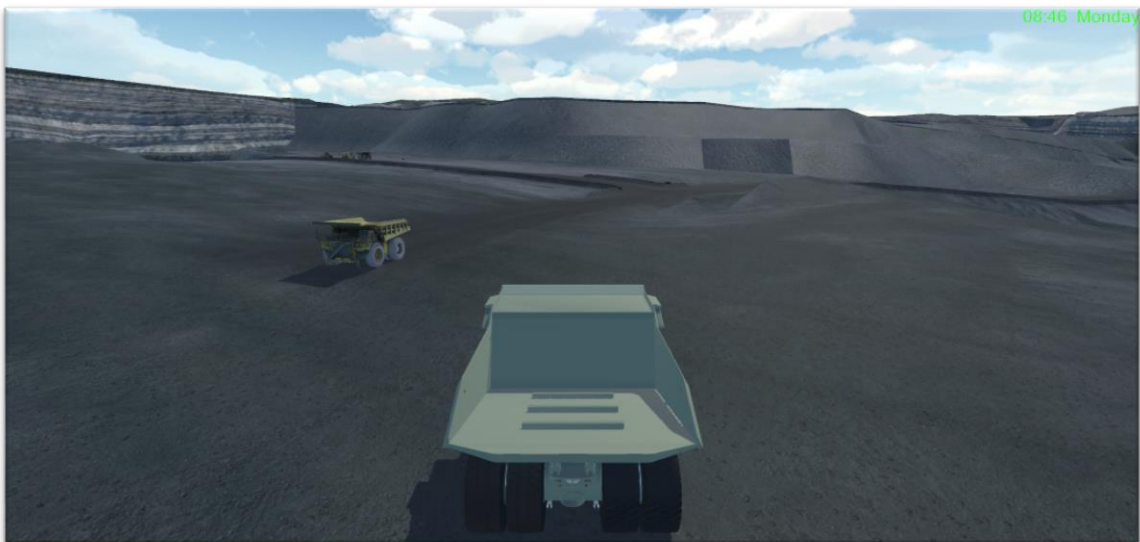

Figure 8. Truck mode - third person view

Figure 9. Truck mode - Driver (First-person) view

Slope Monitoring Mode

Slope monitoring mode brings up a virtual camera hovering above the projected failure zone with a slope displacement graph and likelihood-consequence matrix shown as a heads-up display (HUD). In addition to this the prism monitoring points are visible with their rate of movement (RoM) in millimetres per hour shown as well (Figure 10). The slope displacement graph and prism point RoMs update every hour in-game according to the movement of the slope.

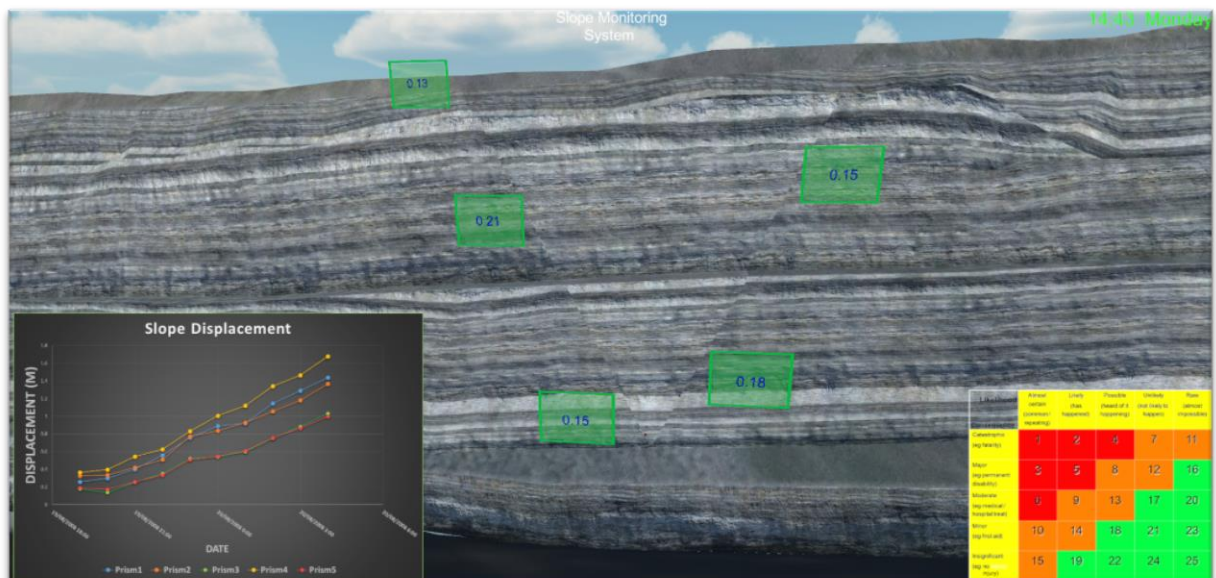At some point during the 7 day simulation the wedge failure will occur.

Figure 10. Slope monitoring mode

APPENDIX C

Mining Methods and Equipment Questionnaire (Pre+ Post-VR)

Grade: _____

For each of the following questions circle the correct answer from options provided.

Q1. Choose the correct mining equipment name for each picture:

	A. Electric Rope Shovel B. Continuous Miner C. Longwall Shearer D Dozer
	A. Dragline B. Electric Rope Shovel C. Hydraulic Excavator D. Haul truck
	A. Grader B. Rotary Drill C. Dozer D. Water cart

	A. Dragline B. Continuous Miner C. Rock drill D. Breaker-feeder
	A. Hydraulic disk cutter B. Wall cutter C. Longwall Shearer D. Rock cutting machine

Q2. Which of the following is NOT an Underground Coal Mining Method?

A. Longwall Mining

B. Strip Mining

C. Punch-Longwall Mining

D. Bord and Pillar Mining

Q3. Which of the following is used for ground support in underground mines?

A. Rock Bolts

B. Steel Mesh

C. Shotcrete

D. All of the above

Q4. What is the main access to an underground longwall mine called?

A. Decline

B. Maingate

C. Tailgate

D. Development Face

Q5. When waste rock is dumped into previously mined out areas it is called a/an:

    A. Previous dump

    B. In-pit dump

    C. Ex-pit dump

    D. S-pit dump

Q6. Which of the following is an example of infrastructure on a mine site?

    A. Tailings Dam

    B. Processing Plant

    C. Maintenance Workshop

    D. All of the above

Q7. Which OPEN CUT mining method is commonly used in Queensland?

    A. Truck & shovel mining

    B. Highwall Mining

    C. Block Cave

    D. Bord and Pillar

Q8. What is Australia's largest mining export?

    A. Coking Coal

    B. Iron Ore

    C. Thermal Coal

    D. Uranium

Q9. Which of the following is NOT an example of energies on a mine site?

    A. Biological

    B. Electrical

    C. Chemical

    D. Empirical

Q10. What is the waste material that needs to be removed before ore can be mined called?

    A. Aburden

    B. Top rocks

    C. Overburden

    D. Underburden

Thanks for your time ☺

APPENDIX D

Post-VR Survey Q2 & Q3

Any other comments or suggestions regarding the VR session?

Not much background to know what we were looking for in initial TARP outline - example case copy pasted from another source. The limits for each criteria were unclear and the session didnt have much structure in terms of the activities we were meant to accomplish

11/3/2015 10:51 AM View respondent's answers

I didn't enjoy the scenario as it made me feel sick and gave me motion sickness. It was a long winded way of watching the wall collapse and probably could of been shown in a 30 second video. While the use of the controllers were fun, it probably wasn't necessary.

11/2/2015 2:09 PM View respondent's answers

Nope

11/2/2015 11:40 AM View respondent's answers

The VR session only focused on one risk variable that being the graph. TARP's on site focus more on observing cracks and dribblling rocks - none of this could be viewed in the simulation. Geotechnical engineers use the inverse velocity plot to predict failures rather than a displacement time curve as acceleration is the best indicator. RADAR manufacturers do not make judgments on what accelerations are dangerous - it is site specific. Wanting us to include accelerations in the TARP without any background information or rock failure history set us up to lose marks in the initial TARP submission. The graph led to guess work rather than actually identifying triggers. The classroom session was long and boring. We spent out time climbing up highwalls rather than watching for triggers.

11/2/2015 11:11 AM View respondent's answers

I feel like this would be a crucial lesson to give earlier in the bachelors degree as it gives us a realistic image of all the facets of mining that we will soon be learning about. Maybe one for hardrock and one for coal. It helps paint a picture in the mind of everything and would make learning about it from lectures less abstract and more relatable.

11/2/2015 11:07 AM View respondent's answers

Allow multiple users

11/2/2015 10:45 AM View respondent's answers

The VR session seemed pointless and a waste of time. We could have watched a prerecorded video and got the same results.

10/19/2015 6:43 AM View respondent's answers

Maybe if you gave the inverse velocity plot to make this more applicable to industry. I know this narrows down our estimation of failure. Possibly cut the inverse velocity plot up to give a ball park figure of when failure will occur.

10/15/2015 5:18 PM View respondent's answers

The VR session was very engaging and took a new look at to a particular scenario.

10/15/2015 2:26 PM View respondent's answers

Some more explanation of the task beforehand

9/21/2015 9:58 PM View respondent's answers

It would have been good to have other "tasks" to complete during the session- could be incorporated with other risk assessment activities to further enhance learning.

9/21/2015 3:13 PM View respondent's answers

If possible, I would like to see how all the equipment functions up to the time of failure.

9/21/2015 3:00 PM View respondent's answers

More learning activities/objectives whilst the simuation is running up until failure would make the session more engaging.

9/21/2015 11:34 AM View respondent's answers

The idea of VR assessment is awesome and I think it's a great idea. However, the lack of information about the failure made this particular prac a little difficult and maybe not as engaging as it could have been. I think inverse velocity or acceleration data would have given a better result.

9/18/2015 2:14 PM View respondent's answers

For the VR session to be more applicable to everyday assessment, I think the students need some more direction and some learning based lecture going on at the same time to help with the TARP. More direction so that we know what we should be changing in our TARPs.

9/18/2015 1:08 PM View respondent's answers

Perhaps increase the rate in which time past. It felt like a long practical session for something that could have been learnt in half the time. Maybe double or triple the speed. Apart from that it was an awesome experience.

9/17/2015 8:21 PM View respondent's answers

possibly have tasks that students need to complete in the VR

9/17/2015 5:57 PM View respondent's answers

I understand that VR is only a preliminary program. I would like to see more uses of this and explore mining topics such as blasting, operating the equipments, be part of the operation and understand the processes through VR

9/17/2015 5:12 PM View respondent's answers

It seemed unnecessary. Was more of a test for the VR

9/17/2015 2:04 PM View respondent's answers

The session can be shorten

9/17/2015 12:20 PM View respondent's answers

The proximity to the screen -- coupled with jittery controls -- gave me motion sickness.

9/17/2015 11:38 AM View respondent's answers

implement more tools for tracking relevant information

9/17/2015 11:25 AM View respondent's answers

including me, some of students feeling dizzy

9/17/2015 10:57 AM View respondent's answers

Good for providing a new method of interactively analyzing risk at a mine site

9/17/2015 9:23 AM View respondent's answers

n/a

9/16/2015 8:08 PM View respondent's answers

What other mining or mining related scenarios would you like to see in VR?

Underground mining system

11/3/2015 7:44 AM View respondent's answers

If people have not yet seen a mine site it is good for them to view it.

11/2/2015 2:09 PM View respondent's answers

Nothing

11/2/2015 11:40 AM View respondent's answers

A scenario where we can monitor triggers that actually happen on site. For example effective temperature or methane content underground.

11/2/2015 11:11 AM View respondent's answers

Blasting would be cool

11/2/2015 10:46 AM View respondent's answers

Underground coal mine emergency

11/2/2015 10:45 AM View respondent's answers

Don't know.

10/19/2015 6:43 AM View respondent's answers

Roof convergence leading to failure.

10/15/2015 5:18 PM View respondent's answers

Perhaps a traffic incident on haul roads where a collision is possible due to high traffic volume.

10/15/2015 2:26 PM View respondent's answers

underground system

10/15/2015 2:25 PM View respondent's answers

Mine fire

9/21/2015 9:58 PM View respondent's answers

Scenarios involving underground operations or development would be very good!

9/21/2015 8:24 PM View respondent's answers

Would like to see some emergency factors- perhaps how to deal with environmental risks or something along those lines.

9/21/2015 3:13 PM View respondent's answers

Underground roof falls

9/21/2015 3:00 PM View respondent's answers

Different mining methods, it would be much easier in the course to learn different mining methods and the process in each method if you can walk through it yourself in a VR

9/21/2015 11:54 AM View respondent's answers

gas

9/21/2015 11:43 AM View respondent's answers

Any dynamic events could be interesting, if done in the right way.

9/21/2015 11:34 AM View respondent's answers

Underground hard rock mining methods. Blasting. Loading and digging sequencing. Dragline Casting.

9/21/2015 11:33 AM View respondent's answers

Block cave air pocket - air blast risk

9/18/2015 2:14 PM View respondent's answers

Blasting simulation with vibration induced failures.

9/18/2015 1:08 PM View respondent's answers

Longwall face stability if this is even possible?

9/17/2015 8:21 PM View respondent's answers

general operating of a mine would be good, seeing how machinery interacts (i.e. a shovel loading a truck or a jumbo drilling a round underground)

9/17/2015 5:57 PM View respondent's answers

Blasting, changing the blast design and seeing it in use. Operate more equipments and understand more about the process. Would like to see more interaction with AI to highlight the importance of safety and the limited vision from the cabs by the vehicle operators.

9/17/2015 5:12 PM View respondent's answers

Would be interesting for emergency situations

9/17/2015 2:04 PM View respondent's answers

Mine operations and development

9/17/2015 1:06 PM View respondent's answers

The ability to see activities in real time would make this technology extremely useful in the first year of mining engineering for teaching students about various mining methods.

9/17/2015 11:38 AM View respondent's answers

process flows for various mining methods and method variants

9/17/2015 11:25 AM View respondent's answers

production drilling and charging

9/17/2015 10:57 AM View respondent's answers

Would be good to use VR in 3122 Mining System course

9/17/2015 10:31 AM View respondent's answers

This type of software would be extremely useful for learning the mechanics and equipment involved in mining methods.

9/17/2015 10:20 AM View respondent's answers

Mining method overviews/visualization for teaching

9/17/2015 9:23 AM View respondent's answers

Blasting

9/16/2015 8:08 PM View respondent's answers

End.