FEASIBILITY STUDY: DEVELOPMENT AND DEMONSTRATION OF VIRTUAL REALITY SIMULATION TRAINING FOR THE BHPB OLYMPIC DAM SITE INDUCTIONS

Dr Phillip M. Stothard, UNSW School of Mining Engineering. Chief Investigator.

Prof. Anton van den Hengel, University of Adelaide, ACVT. Chief Investigator.

A collaborative project between,

UNSW - School of Mining Engineering, University of Adelaide - ACVT,

BHP Billiton - Olympic Dam, RESA, TAFESA, SkillsDMC.

Delivery of this report marks the completion of the project.

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Project Steering Committee

Prof Peter Dowd, Executive Dean, Faculty of Engineering, Computer and Mathematical Sciences, University of Adelaide.

Steve Beere, CEO, RESA, Adelaide, SA.

Adrian Francis, RESA, Adelaide, SA.

Dorothy Rao, Operations Manager, SkillsDMC, NSW.

Denise Janek, CEO, TAFESA. SA.

Ian Henderson, General Manager, TAFESA Regional, Adelaide

Bernard Croese, Consultant (Formerly, BHPB Olympic Dam Expansion, SA).

Colin Maddox, Manager, (Formerly, Learning & Development, BHP Billiton OD Expansion, Adelaide)

Glen Michels, Superintendent Shutdown and Training Dept, BHPB, Olympic Dam, SA.

Rob Paul, Consultant (Formerly, BHPB Olympic Dam Expansion, SA).

Research and Development Team/ (Contributors)

Dr John Bastian, Dr Chris Fowler, (Prof Jim Kehoe),

Lauren Poynton, Shirley Zhang,

Albert Morrissey, Darren Lee, Kei Ohnishi, James O'Rourke, Felix Yakub,

Trainers

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1. Executive Summary

This report presents the findings of the project "Feasibility Study: Development and Demonstration of Virtual Reality Simulation Training for the BHPB Olympic Dam Site Inductions." The project was a collaborative exercise between the University of New South Wales (UNSW) - School of Mining Engineering, the University of Adelaide - Australian Centre for Visual Technologies, BHPB Olympic Dam Expansion, RESA, TAFESA and Skills DMC.

The project Chief Investigators were Dr Phillip Stothard (UNSW) and Prof Anton van den Hengel (University of Adelaide).

The project was a pilot study research project that looked into the feasibility of developing interactive virtual reality simulations for mine site inductions in the hard rock industry. Many simulations have been successfully implemented into the coal industry and the aim was to build a pilot module that looked at a high risk environment on a surface mine that would also have application to the wider construction industry and other heavy industries.

The project collaborators came together as a group of parties interested in virtual reality simulation. The research and development was led by UNSW and University of Adelaide. Invaluable input was provided by the collaborators.

The project had a value of $431, 306. Of which $208,563 was in cash and $222,743 was in kind. The budget was fully expended during the course of the project.

The subject area of the project was 'Working at Heights' and this was chosen because it is a high risk area. Substantial documentation, mining industry input and effort was placed on building the five sub-modules that form the Working at Heights module. The outcome is a high quality visualisation of an area of the Olympic Dam Mine Site. This high quality visualisation is enhanced by the inclusion of interaction within the module that requires the user to interrogate data within the site and to assess and understand issues that arise when working at heights in relation ladders, scaffolding, open excavations and elevated work platforms.

Much project emphasis and time was placed on producing the 3D model. Also, as much information as possible was placed into the module itself as this was to be a pilot example to show to the Olympic Dam Expansion Project Team. The module allows users to interact with Safety Documentation and equipment and procedures that they would encounter on site.

Unfortunately, the module suffered the unforeseen impact of the global financial crisis with the Olympic Dam Expansion Project Team being disbanded and retrenched. The Olympic Dam Site has since accommodated the project, but the momentum in the project was unavoidably impeded due to budget and personnel restrictions. The module has however successfully deployed to site in a usable from.

The module was built in 3D Studio Max and Maya which are common 3D modelling packages. The rapid prototyping was performed in a virtual reality / game engine known as Virtools. At the outset Virtools was used so that the capability of the Mining VR team at UNSW could be leveraged and also any ‘Working at Heights’ pilot module could be shown on a scaleable visualisation platform ranging from a 360 fully immersive system, down to a mobile laptop computer. Unfortunately, again the financial economic crisis impacted during the project duration. The suppliers of Virtools went into liquidation and the licensing costs pertaining to Virtools have become unwieldy due to the new suppliers no-longer honouring the licensing arrangements agreed with the previous supplier (This is being re-negotiated at the time of writing).

One of the project tasks performed to combat this potential issue with Virtools, was that an evaluation of available game engines with favourable functionality, licensing, access and community support was performed. The outcome of this part of the project was to recommend that in any subsequent continuation in the development of the module, a substitute game engine should seriously be considered. The report recommends that – depending on the planned visualisation platform for any formal deployment, the engine used should be either, Unreal Engine 3, Virtools or Ogre. If the clustering of PCs is not required, then the game engine Unity should also be considered. Ogre is considered the best ‘overall’ when considering platforms, price, quality and so-on.

The development of the module leveraged OEM drawings, site drawings, photographs, videos and access to equipment hire companies. The development team produced a fully interactive 3D model of the environment to a high level of resolution and fidelity. The development of 3D models for the population of the model is time consuming and an evaluation of University of Adelaide’s ACVT VideoTrace software was performed from a developer and user perspective. The outcome of these investigations was that VideoTrace is potentially a very powerful and fast tool for producing 3D models and although the study found limitations in its application and some areas that required further development work, the models produced to populate the model for level of detail and scene complexity were very good. The recommendation is that ACVT’s VideoTrace software continues to be developed and improved inline with the developer and user comments in the report as a matter of urgency.

An aspect of interactive 3D simulation development that must be considered is the educational evaluation of the module. The Working at Heights module was subjected to an experimental site deployment in Adelaide where engineering apprentices were exposed to the simulation. A course was designed that implemented the simulation as part of a Working at Heights course. The outcomes from this evaluation from a trainee and trainer perspective were extremely valuable.

The deployment showed how the interactive nature and instructional design of the module needed to be considered much more carefully with respect to cognitive load theory. That is, the training course and the module should consider the course design with respect to educational principles and engagement of the trainee. The result from the experimental deployment was that one of the sub-modules was redesigned slightly and took into cognitive load theory considerations such as intrinsic cognitive load, extraneous cognitive load and germane cognitive load. The module was then formally assessed for its benefits compared to traditional PowerPoint delivery. The outcomes produced some interesting results – the most important being that when people are allowed to interact and use the simulation in flat-screen format as individuals, their performance is improved when compared to group PowerPoint delivery and Group VR delivery. This is of particular interest because, when these results are compared to a parallel study (outside of this project) where large screen immersive systems were used, groups performed best in the virtual reality simulation with respect to problem solving and knowledge retention when compared to PowerPoint. Hence course design and the development of appropriate course materials for the expected audience must be considered in much more detail in any further development.

The ‘Working at Heights’ module was deployed on site at Olympic Dam and implemented into the Working at Heights course. The outcomes of this deployment were positive and revealed that for any module deployment, the module must be ideally be implemented into a purpose built facility. The installation at Olympic Dam was temporary and not an ideal set up. The developed content and simulation course must be developed in consultation with the trainers who will use the module. However, aspects of simulation course design pertaining to cognitive theory must be implemented. The course design must also reflect and consider the people that will use the simulation. That is, the people on site are practical and like to experience things hands on.

Any subsequent virtual reality course material should get the trainees to problem solve and interact personally with the material at a level relevant to their prior knowledge. The cognitive load on the trainees must also be considered both within the simulation module and the course as a whole. They must engage with the training material and be able to directly relate and apply the solution of problems encountered and learned about in the simulation, to a real mine site. They need to transfer safe human responses from the simulator to their work environment for the outcome to be truly positive.

In conclusion a high quality pilot simulation and pilot project feasibility study has been performed. The outcome has been the identification of software components, the building of a Working at Heights module through industry consultation and the educational evaluation of the module. The module has also been deployed at Olympic Dam in Pilot format and a future direction for the module identified.

The recommendations are,

1. A project risk assessment should be performed prior to commencing any future project.
2. Development of the Working at Heights and other modules should continue.
3. Psychological and educational design of the module with respect to cognitive load theory is a priority and experienced researchers and educational psychologists at University level should be closely involved in any subsequent virtual reality course material development.
4. Development of simulation course material should be performed in collaboration with industry trainers and adult educational establishments to achieve the best outcome. A formal simulation course should also be designed that incorporates the existing simulation - Working at Heights.
5. A commercial entity should be used to produce both the model and module based on a formal specification derived prior to any work being performed. This should be a priority.
6. Any future module should be deployed via a large screen group environment on site in a purpose built facility.
7. Developed modules should also be made accessible offsite (as appropriate) to ensure that modules are available to the widest possible audience.
8. A formal experimental process at University level should be developed to assess the possibility of using simulation to assess competency in Working at Heights and other high risk activities. At present the modules do not do this and a great deal of work needs to be done to address this area.
9. Federal and State Government Funding should be the target for future simulation projects. This should be combined with industrial funding where possible.
10. Any future project should be a strategic project of approximately three years.

The support of all the collaborators and contributors is gratefully acknowledged.

2. Introduction

This report presents the findings of a 12 month collaborative research project that aimed to develop and demonstrate an interactive mixed reality simulation training module for site inductions. The project was led by the University of New South Wales (UNSW), School of Mining Engineering, and the Australian Centre for Visual Technologies (ACVT) at the University of Adelaide. The project was performed in collaboration with BHP Billiton ODX, RESA, TAFE SA, Skills DMC. The support of all the collaborators is gratefully acknowledged.

The Chief Investigators on the project were, Dr Phillip Stothard who has an established track record as a Project Director in the research, development and implementation of the VR facility at UNSW and also transferring the technology to industry and Prof Anton van den Hengel who is the Director of the Australian Centre for Visual Technologies.

An immersive, interactive simulation module has been developed based upon the generic issues of working at heights on mine, construction and other heavy industry sites. Working at heights was chosen because it has the potential to be a high risk activity. The working at heights simulation scenario was developed as a proof of concept project to identify issues associated with transferring simulation training modules to the 'hard rock' industry. Many simulations have been developed for the Coal Industry and the technology is already established in other high risk industries. The training scenario module development is the main focus of this project report with visualisation technology being covered elsewhere and separate from this report.

Producing interactive virtual reality simulations from a 'blank sheet' is a complex procedure and the processes that work in one industry do not necessarily transfer directly to another. Hence the report covers the main topics of simulation model development, refinement and deployment on site.

The long term aim of developing the working at heights simulation is to ultimately transfer the concept to the mining industry through the implementation of virtual reality facilities at training sites. It was intended that the simulation scenarios established by the research could be easily be adapted to the needs of other Australian heavy industry in future projects.

This first stage project had a total value of $431,306 of which $208,563 was cash and $222,743 was in kind.

The Working at Heights module developed by the research focussed on the correct use of ladders, scaffolds, elevated work platforms, and safety harnesses. This subject was chosen as a demonstration subject for this pilot research project due to the significant OH&S implications of the subject and broad range of organisations with an interest in the topic.

Highly experienced mining industry personnel were engaged in the development of the module. These personnel formed the conduit required to bring the high-level gaming technology and site based experience together to develop a working pilot module.

Computer based mixed reality simulation and computer gaming has the potential to be a powerful tool for conditioning human behaviour. Both technologies enable users to experience a range of situations that would otherwise be impossible, or prohibitively dangerous or expensive. Workers can condition their responses to these situations in a safe and forgiving environment. Exposure to normal operating conditions also allows a user to de-sensitise before being exposed to an otherwise strange environment.

A new technology VideoTrace developed by ACVT is also evaluated as part of the project as is the educational design of the module developed under the project.

The project has revealed some interesting outcomes in relation to developing projects under the collaborative mechanism and recommendations for future projects are made.

3. Project Objectives

The ultimate objective of this collaborative project is to improve safety on industrial sites and in particular on mine sites. It is believed that the reduction of risk to personnel can be achieved through improved understanding of the complex safety rules, processes and procedures that operate on modern industrial sites.

By presenting these issues in a graphical form via virtual or mixed reality it is possible to provide a tool that may improve and enhance current training practices. Safe human responses may hence be achievable through improved knowledge and understanding. This improved knowledge and understanding should flow onto to improved levels of competence when personnel are operating on site through improved understanding and situational awareness. However, it is not the intention of the module to demonstrate competency at this stage nor should this be implied.

From an operations perspective, the primary objectives of the project was to,

- Develop, demonstrate and transfer a pilot capability in immersive, interactive, virtual and mixed reality simulation to improve OH&S management and performance in the Australian mining and construction sectors through providing more effective education, training and assessment. The "Working at Heights" module presents a concept and tool for trainers and educators to achieve this and the pilot simulation "Working at Heights" has been developed relating to working at heights and has drawn upon protocols developed by BHP Billiton, TAFE SA, SkillsDMC and other OH&S documentation.
- Transfer the simulation to a working site and The "Working at Heights" simulation module has been transferred to BHP Billiton Olympic Dam Mine in a form that may be deployed on workstation computers, and virtual reality theatres. The simulations have been demonstrated in both controlled experimental and formal training environments.
- Deploy to a wider audience, within mining and construction through presentation of the developing module at SIMTECT 2009 via the Virtual Reality Facility at the University of Adelaide.

From a project perspective, the secondary objectives were to,

- Provide the software and hardware foundations to adapt the technology to other activities of the mining industry.
- Use the opportunity to take mining and construction engineering training, education and research into a new field.

- Utilise the technology to improve the effectiveness of training in the Australian industry and overseas. VR Simulation allows the mine or site to be brought to the classroom.
- Improve the effective use of training research and development funds through a collaborative project between UNSW, Uni' Adelaide, BHPB, RESA, Skills DMC and TAFE SA.
- Leverage industry funds to gain increased State and Federal Government funding for the development of VR training facilities for use in mine and construction training and education.

During the project, there was an unfortunate turn of events in the form of the BHPB Olympic Dam Expansion Project team being retrenched with inevitable consequences that impacted severely on the project and while most of the above objectives have been met. Operational issues have restricted some objectives. This issue is discussed later in the project report.

The project was affected by an unforeseen downturn in the global economy, however, the project has still succeeded and managed to develop a Working at Heights module, evaluate this module and deploy it on site at Olympic Dam.

Overall, most of the objectives have been met despite this unfortunate turn of events.

4. Literature Review

Mining in the 21st century is a high technology industry and a truly global business. Mining companies, large and small, all strive to increase and maintain production and remain competitive within the global economy while ensuring and maintaining their worker's safety. In recent decades, improvements in mine safety have resulted from legislation, development of risk management techniques and improved technology. This is demonstrated by BHP Billiton, one of the collaborators of this project and a source of world class safety information that is implemented globally.

The development of intricate rules and regulations and their strict implementation on site has led to improvements in overall safety however, there is serious concern that accidents still occur – sometimes with extremely serious or fatal consequences. Working at Heights, which is the focus area of this project is unfortunately no exception to this.

It is believed by the researchers and collaborators that there is a need for an innovative use of technology to provide improved and enhanced education, training and assessment in mining (and other high risk) activities. The aim is to reduce risk and the use of virtual reality and mixed reality simulation to represent mine site activities offers an opportunity to develop tools and systems that can improve knowledge and understanding of the work environment. In theory, this should lead to an improved knowledge and understanding that may ultimately lead to improved human responses and an increasingly safer work environment. If the design and implementation of the technology is approached correctly this may eventually provide a mechanism to assess and prove competency to some level, however, the replacement of site based real-world competency is not the purpose of virtual reality at this stage of development.

The catalyst for the development of the interactive Working at Heights simulation discussed in this project is based on a concern that the traditional methods of training mine workers may be inadequate due to the complexity and intricacy of the rules and regulations that have been introduced. The shear volume of rules and regulations and their complexity may make them difficult for people to study and interpret. An improved method is required for the representation of these rules and procedures. Virtual reality and mixed reality offer an opportunity to present this information in a graphical as opposed to a text-based format that may be easier for the uninitiated to comprehend, understand and apply to their work environment. Virtual reality and mixed reality simulation for training and visualisation purposes has been implemented successfully by several industries but is still slow to be realised by mining, although their have been significant advances over recent years.

This literature review aims to provide the collaborators with an insight into the types of technology employed on virtual reality installations at various locations. The review is not exhaustive as there are very many papers written on virtual reality applications as a trawl of learned electronic journals, conference proceedings and the Internet will reveal. It should also be noted that the review is not particularly aimed at vehicle or equipment operator training. The aim of this project is to look at virtual reality for spatial and operational awareness on site. The review also covers some examples of virtual reality technology applied to other industries.

Virtual reality technology is a computer-based technology that has been in existence for many years. As computer hardware technology and software technology has improved, the ease with which interactive simulations can be developed and deployed has become much more straight forward and low cost high quality 'tools' are available off the shelf for anyone interested in building scenarios to 'jump on board'. Unfortunately, the innovation and experience required to develop meaningful simulations in this fledgling technology is not so easily acquired and many projects find that they can develop images and visualisation systems relatively easily and instil a 'Wow-factor" however adding real value to the processes working behind the simulations is often overlooked and sustainability of the developed systems is difficult to maintain unless approached cautiously. The importance of the psychological processes and educational design behind these simulations can also not be understated. What the simulations actually 'give' to the people who interact with them is fundamental.

Several case studies are presented where simulation has been developed for research and industrial applications. Virtual reality simulations have been developed by many organisations to varying degrees of success and the format is variable. This project investigates the "Development and Demonstration of an Interactive Mixed Reality Simulation Training Module for Site Inductions" – the developed module is called Working at Heights and was a result of targeting a safety issue that unfortunately occurs on mine sites and which is not always obvious to mine workers but nevertheless has very serious consequences.

General Concept and Historic Examples

The concept of using simulation and games for training mine workers has been around for well over a decade now. Bise (1997) and Denby et al (1998) describe the concept of a virtual reality training scenario. Denby et al (1998) proposed a "Hazard Awareness Training for Mining Situations using 'virtual reality' ". The aim was to produce simulations of mining situations for training and the idea was to leverage Personal (PC) computer game technology to make simulations accessible to all industries large and small.

The use of virtual training simulations for mining applications was pioneered at the University of Nottingham in the United Kingdom where a low cost simulator was developed by Denby and Schofield (1998). Denby and Schofield (1998) and Schofield (2001) discuss the concept of these simulators in detail. Most of the work in these early projects was based on the development of mining VR based systems that were focussed on the identification and avoidance of hazards. These early simulations were ground-breaking in their approach and a screen-shot of one of these early simulators is shown in Figure 1a and b.

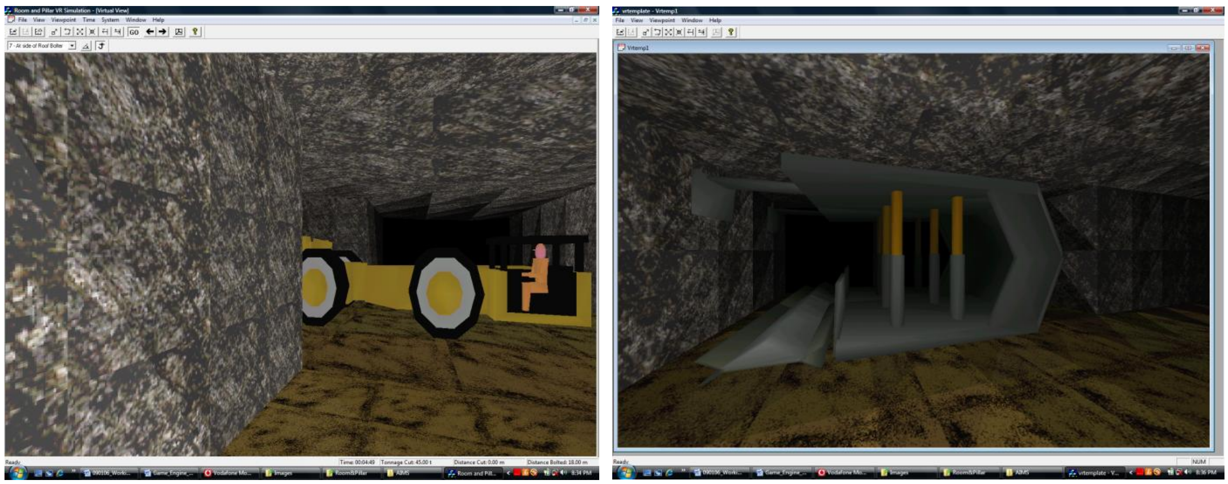

Figure 1a. Underground Virtual Environments c2000. (After AIMS Research c2000)

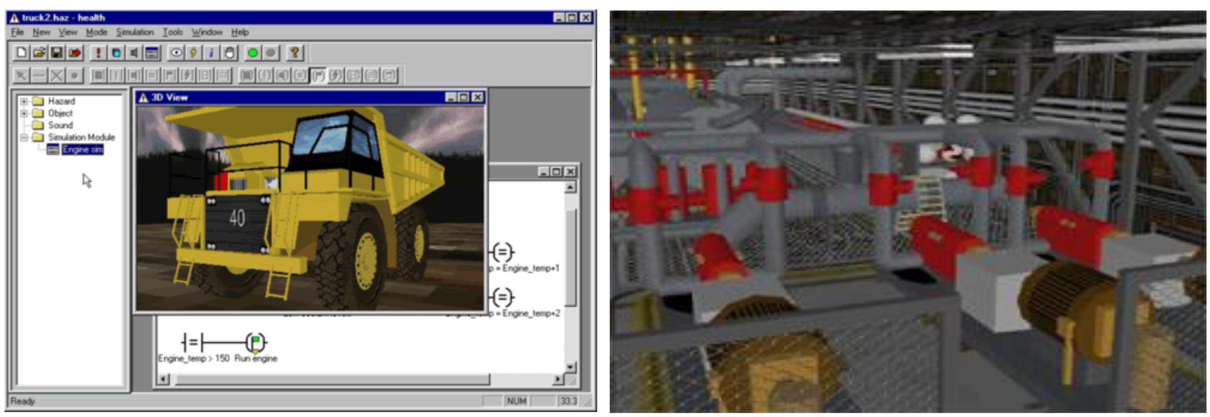

Figure 1b Truck Inspection and MOL Pump Operation Simulation (After AIMS Research c2000)

Denby et al (1998) leveraged the fledgling PC based games market to develop the simulations. The Games market has since lead to some significant developments in PC games technology and hence simulations – many modern simulations are founded upon this concept. The objective of the Denby et al (1998) simulations was for the user to navigate around a virtual mine and spot hazards. This has since become a ‘standard’ approach within many simulations, although the practice of using serious games and development in cognitive theory is now producing more sophisticated interaction and instructional design.

Squelch (2000a) developed a virtual reality model based on a South African gold mine operation in which the objective of the virtual reality simulation was for miners to spot unsafe ground and mining practices. In Squelch’s (2000a) simulation, the issue of miner literacy were considered and a graphical interface used for interaction.

In the United States, a group of researchers at the National Institute for Occupational Safety and Health (NIOSH) developed an early prototype simulation aimed at training surface and underground workers in evacuation procedures and hazard recognition (Filigenzi et al 2000).

MIRARCO approached virtual reality slightly differently and developed a virtual reality lab (VRL) at the Laurentian University. The system was aimed at mine geometry, geology, geochemistry, geo-mechanics and mining and mine safety applications. One of the projects at MIRARCO was the development of an equipment visibility systems and a load haul dump LHD machine was modelled (Delabbio et al 2003).

Figure 2. Early UNSW School of Mining Simulator. c2001.

The University of New South Wales developed a prototype hazard spotting simulation based on a New South Wales Coal Mine that was based on the University of Nottingham and approach.

The objective was to spot hazards around a personnel carrier underground (Stothard 2001b). Figure 2

These early simulations defined a way forward for mining simulators around the world and the format that they should take. From the literature it is clear that the early development of virtual reality training environments for mining aimed to move away from proprietary systems used in Aviation and Military applications and towards "Commercial off the shelf" or COTS systems. However, in the early stages, it was only the beginning of the COTS software and hardware for simulation and the results were limited still very limited.

Many of the developed systems had their focus on presenting computer generated virtual models of the mining environment and many of the key researchers in mining industry virtual reality simulation had significant success in developing these types of simulations. Examples of early mining simulations are presented by, Kizil (2003), Schofield et al (2001), Schmid and Bracher (2004), Schmid and Winkler (2008), Squelch (2001), Stothard et al (2001), Stothard et al (2004), Stothard (2007), Unger and Mallet (2004) and Van Wyk (2006). These researchers are from various research institutions around the world and most have found that legislation and the need for improved safety and production has driven their simulation development and focussed the simulation content requirements. In particular the need to address this issue of improved safety through improved understanding of complex issues is presented.

The idea of using mining virtual reality for mining applications was described by Bise (1997) and despite this extended period, the adoption of the technology to mining has been very slow when compared to other industries such as Aviation, Health, Military and Rail (see SIMTECT 2000-2009).

Many of the early virtual reality simulations proposed and developed by researchers such as Bise (1997), Denby and Schofield (1998), Schofield et al (2001), Stothard et al (2001) and Squelch (2001) made use of synthetic computer generated environments that contained video clips, photos and web-based data relating to real world information. The concept was to develop an interactive simulation that user's could interact with to learn about a particular aspect of an operation. The broad concept of a simulator is shown in Figure3 and is taken from Stothard et al (2001).

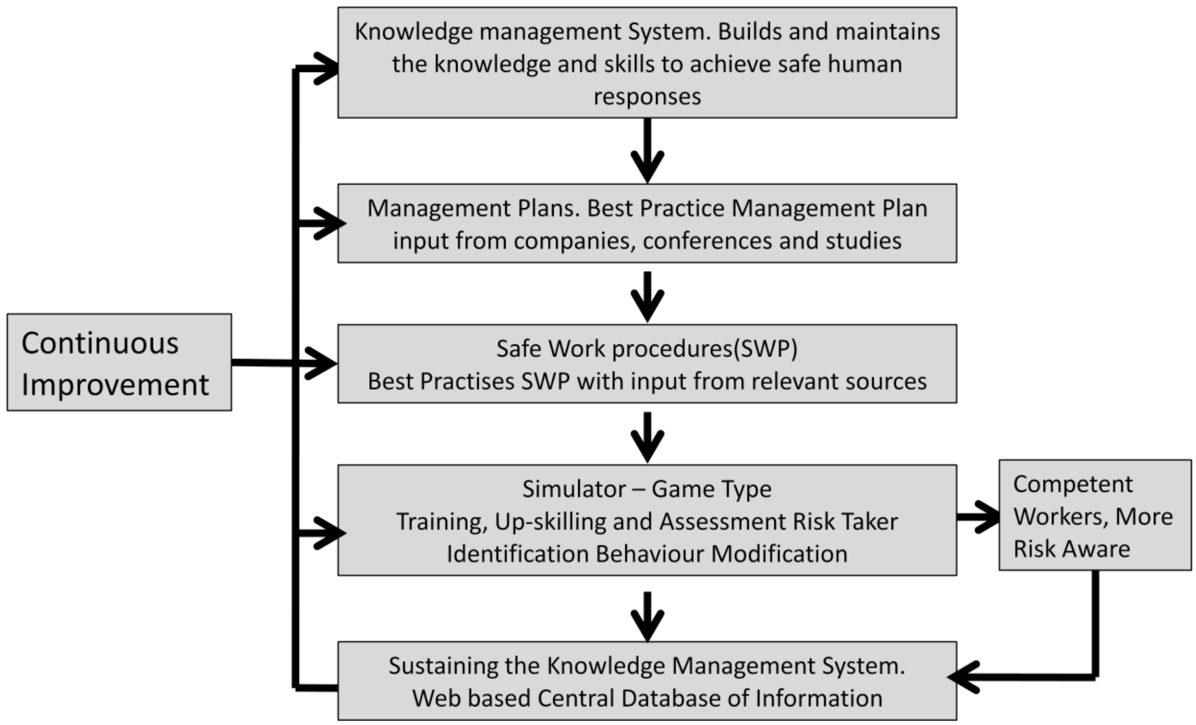

Figure 3. General concept of an interactive training simulator for the mining industry (After Stothard et al 2001).

The computer generated environments built by most researchers were representations of high-risk environments in the mining operations. Some researchers such as Stothard et al (2001) performed Scoping Studies that also considered the full spectrum of available technology for the mining industry and also considered the content that should be included in the system and how it should be maintained to ensure sustainability. The considered systems ranged from high end proprietary systems provided by companies such as Silicon Graphics through smaller intermediate systems and down to the low cost game based systems described by Denby et al (1998), Squelch 2000a and Schofield et al (2001).

As more and more systems were being developed around the world, the focus has remained on developing technology and content and despite there being a low start-up cost, there had been little (apparent) attention given to what the system capabilities really were. There remained a significant gap in the knowledge of what the systems could do outside of research institutions and pioneering companies prepared to take on simulations. Hence, sometimes the systems purchased became under utilised due to gaps within industry culture or reticence to accept new methods (Stothard et al (2007) and Schofield (2008)). The ‘general’ format of modern simulation technology is shown in Figure 4.

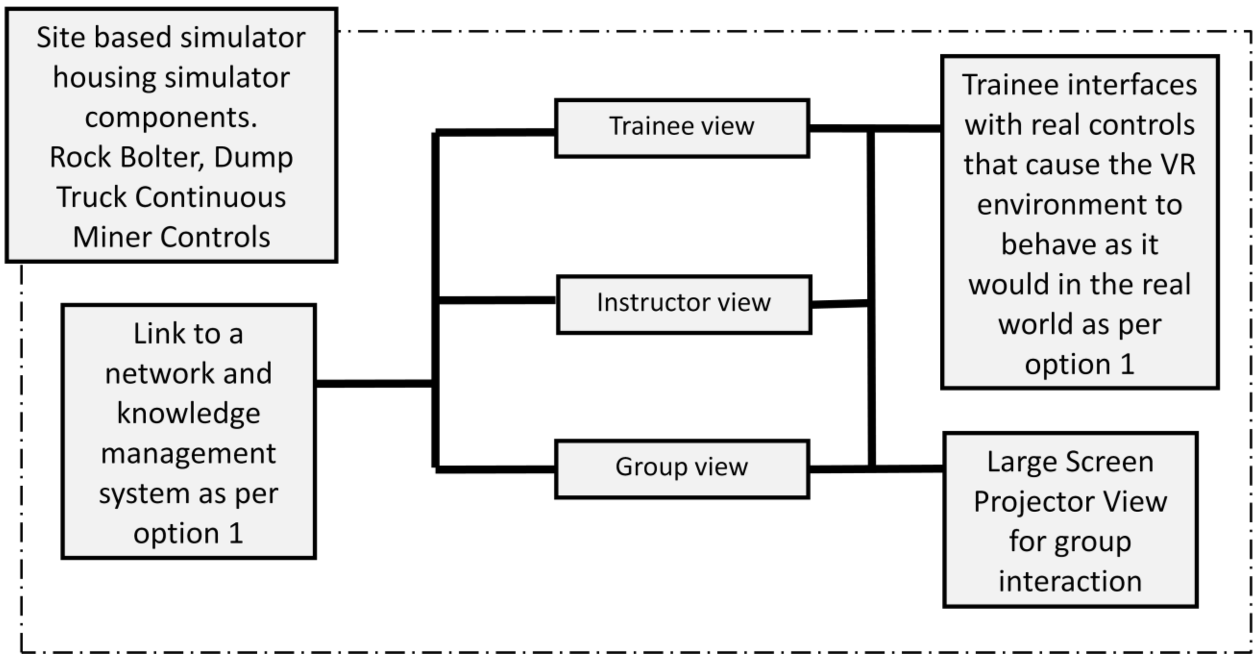

Figure 4. 'General' format of a site based simulator. After Stothard et al (2001).

In many cases, system implementation was restricted by frugal budgets resulting in compromised solutions where a great deal of effort is placed at the beginning of the decision process to use a simulator with only a small consideration of the long term development and support, or integration of the system into operations or curriculum. A needs analysis is sometimes overlooked and the cost and sustainability of developing dynamic and meaningful simulation material to present on the systems is ignored. Logically, without meaningful and considered material, the systems are limited in what they can deliver and achieve. These systems have the potential to become under utilised and can stagnate as technology is superseded. The need for ground level users of visualisation technology to take ownership is paramount as is their input into content generation. The input of industry experts during material development cannot be understated (Stothard et al 2007).

In NSW, Australia, the University for New South Wales (UNSW) has progressively developed and deployed simulations for the coal mining industry. The simulations were developed from a technical concept derived through industry consultation resulting in a hybrid simulator. The simulators were deployed at strategic sites throughout New South Wales. The core objective was to simultaneously train groups of miners in a high resolution environment that had a 'one to one' scale image presented on the screen. The objective of the simulation is to make trainees feel as though they are located in the mine and provide them with an immersive experience (Stothard and Mitra, 2008).

The use of games based technology and its rapid advancement has benefited the development of simulations for the mining industry. Unfortunately, the issue of which game engine to use is difficult to ascertain for the un-initiated. There are many game engines on the market and determining the correct one is difficult. An assessment for a game engine to be used 'post-this-project' is presented elsewhere in this report and will be dealt with in detail there. Eves and Meehan (2008) present various selection criteria for the selection of computer games suitable for simulation. Their technique shows that an initial trawl of the Internet and documentation yields many hundreds of game engines claiming to be able to do many things. The cost of these engines and their licensing, support, capability and reliability is highly variable and difficult to ascertain. The approach taken by Eves and Meehan's (2008) reduces these engines down to a more manageable group size by exclusion through not attaining certain scores in evaluation criteria based on issues such as capabilities in physics, animation, networking and the like some of which are considered essential. The assessment is quite detailed however the results are subjective as the focus was mainly on the technical aspects of the engine. The review is a very useful stating point and innovative assessment. A more pragmatic approach is developed by the project researchers later in this report.

User Engagement with Simulation Characters and Material

The objective of many simulations designed for training requires the engagement of the user and such interaction is a key aspect in making simulations useable and meaningful. The need for realistic characters within the simulation to demonstrate concepts and consequences is often considered to be highly important and artificial intelligence can place human like attributes on computer generated characters and 'bring them to life'. Sweetser et al (2003) discuss research into the modelling of human behaviour in order to create more engaging, entertaining and satisfying games in an attempt to determine what artificial intelligence should be modelled and placed on artificial characters.

The research question asked by Sweetser et al (2003) is, "why do people like playing computer games with other people?" Several factors come into question ranging from intelligence, social interaction, communication and realistic behaviour. These are all factors for developing human-level artificial intelligence. At the time of writing, no formal empirical evidence was available to answer this question and Sweetser et al (2003) aimed to determine which aspects of human behaviour are desirable in other players in computer games and hence artificial characters too. In the case of simulation, it is logical that these attributes would be a starting point for games based simulations.

Sweetser et al (2003) found that there were six broad categories of game including, real time strategy, first person shooter, role-playing game, turn-based strategy, simulations and sports games and that the majority of subjects preferred playing with humans rather than computer players for the reason that a human player exhibits intelligent behaviour. Computer generated characters were reported as boring and predictable. Human social interaction was preferred.

The conclusions of Sweetser et al (2003) were that overall people prefer to play people as opposed to computer generated characters due to a need for social interaction and intelligence within the experience. People prefer to play with other humans because the experience when playing with the computer is often not meaningful.

This has serious implications for training using simulation because unless the simulation is set up in a 'meaningful' manner, trainees may not engage with the material. This also has implication for scenario design, delivery and where simulation may fit into a curriculum or course.

Military Use of VR

McMaster et al (2008) describe the Army's use of computer-based virtual maintenance training as an adjunct to more expensive constructive and hands on training. The key concept is learning by doing using a combination of live, constructive and virtual maintenance trainers. The goal is to offload training on expensive live equipment and constructive mock-ups onto low-cost virtual reality desktop trainers. Virtual Reality Diagnostic Trainers (VRDT) is used as part of an advanced learning environment and provides a component of a complete learning cycle. They also offer a higher student instructor ratio if required and a safe, self-paced learning environment.

Mistakes can be made in the VRDT that would be detrimental in real life. This is analogous to the mining situation. The architecture for VRDT provides the ability to manage day-to-day functions of class management, student records and student reporting. The system has the ability to operate in Institutional Mode, Free-play, and Standalone and can be used for familiarisation basic vehicle operation and trouble shooting and diagnostics.

The advanced learning environment training aids the instructor who can project the VR environment onto the screen and demonstrate system operation and procedures to support the classroom lecture. McMaster et al (2008) describes a classroom based set-up where the student performs the steps along with the instructor to augment the learning experience. Again this is analogous to the format of mining simulators shown in Figure 2.

Lessons learned by McMaster et al (2008) were the need for a viable training plan and determining the training goals at the earliest possible stage of trainer development allows the VRDT to be efficiently designed. This plan should also reflect the strengths and weaknesses of live, virtual and constructive training methods. The training plan should consider safety as a primary goal and virtual training should be used as a gate to ensure that soldiers are well versed in basic safety procedures before they start training on mock-ups or real equipment. Faults that require good motor skills should be trained on real equipment. Good data collection is essential for a realistic virtual trainer and dials and displays must be readable.

McMaster et al (2008) add some additional factors for consideration that are trainer dependent that include, Level of interactivity. What level of interactivity is needed to satisfy a teaching point? What objects need to be interactive? Graphics, 2D versus 3D? What level of detail is required and how many levels?

Finally, McMaster et al (2008) states that the instructors need to be part of the integrated production team and there needs to be ample time in the development cycle for continuing review of the graphics, realism of the simulation and usability of the simulation for training – once the instructors have a vested interest they become advocates of the training device.

Construction VR Simulation

Due to the hazardous nature of construction work, Xie et al (2006) discuss the development of a virtual reality safety training system for construction workers and suggest that as well as utilising traditional and novel training methods, it is important to evaluate the perceptual and behavioural impacts of virtual reality environments on the trainee. By walking through a virtual construction environment and experiencing different scenarios, a trainee can, according to Xie et al (2006), understand and memorise safety rules, standards and regulations in a totally different way. However, how they will actually do and what the different way is unclear in this paper.

Trainees should be able to quickly go through a number of choices and see the final result of those choices is also considered important as is the inclusion of relevant safety and job information along with virtual objects. All of this information should be able to be interrogated by the trainee and Xie et al (2006) believe that ecological and perceptual psychology aspects should also be considered when creating virtual worlds for the construction industry.

With a virtual reality construction system, Xie et al (2006) proposes that employees will be able to explore the outcomes of their decisions without risk to themselves or equipment. They will be able to visualise what cannot be visualised in real life. Workers can experience the different results of their decisions all of which helps develop a better thought processes for decision-making. These all appear sensible, however the method by which they will be measured is not explained by Xie et al (2006).

Educators believe that the following percentages apply in regard to what learners retain from the instruction they receive when presenting training sessions (Table 1). Instruction can be presented in several different ways and the most widely used are lectures/discussion, group instruction, demonstration, conference and multimedia methods and that during instruction, instructors should get the learner actively engaged in seeing, saying, listening and most importantly, doing.

Learning Style	Percentage Retained
Reading	10%
Listening to lectures	20%
Observing	30%
Observing and Listening	50%
Observing and speaking using own words by one-self.	70%
Listening to lectures and doing what is talked about	90%

Table 1. Retaining percentage of learning styles (After Goetsch 1993 in Xie et al (2006))

By its nature, simulation is a structured training activity that simulates a line situation and role playing by trainees and is an activity that can be combined with programmed instruction and interactive video to produce 3-dimensional computer simulations or VR systems. Using VR technologies can help students understand the construction process and the proposed VR system for construction training was to include randomness that creates variations between each scenario and also visual clues of danger and safety procedures to follow. An important variation of earlier (construction VR) systems is that the system shows the user the effects of various choices that the worker makes Xie et al (2006).

When using Collaborative Automated Virtual Environment (CAVE) systems to display the VR models Xie et al (2006) remark that the inclusion of narrative elements to virtual walkthroughs does not take much programming effort and allows the users need for interaction to be met. In these enhanced walkthroughs, teams can explore a project site by either stepping through to predefined viewpoints or navigating in real-time with orbit, examine, or walk functions. Xie et al (2006) also remark that the sense of presence in a virtual worksite should be assessed to determine whether there is a strong sense of presence in immersive VR and to test the usage of

VR through a simple, non-interactive scenario. However, why Xie et al (2006) think a sense of presence is important is unclear. To measure presence, they performed an informal experiment and created two-level virtual scaffolding that was fitted with a dangerous wire hanging on the side of a virtual building.

The level of presence in virtual reality simulations is discussed in more detail later in this report.

Mining Equipment Operation Simulation (1)

Swadling and Dudley (2004) describe the development of VRLoader, a training simulation of a remotely operated Load/Haul/Dump vehicle used to transport ore within a hard-rock mine. The system provided a simulated view of the mine's tunnels and a dynamic model of the motion of the LHD under the controls provided from the operators chair. A quadrant of the mine was modelled allowing the operators to practise traversing the mine tunnels at maximum speed, entering or leaving the drawpoints, and all aspects of operation of the remote controls in driving the vehicle, without risk of damage to the vehicles or the mine. During the simulation, statistics were gathered for the performance of the training sessions to assist with assessment of each driver's progress.

Swadling and Dudley (2004) present a detailed account of the mining operations and equipment and the technical specifications of the equipment that is operated tele-remotely in the mine and then look into the training requirements and performed a training-needs-identification. A group of mine personnel from the various disciplines were brought together and performed a hazard identification and risk assessment process for the tele-remote operation of the load haul dump machine (LHD). The conclusion of the assessment was that the equipment should only be operated by trained competence-assessed personnel.

Swadling and Dudley (2004) comment that it was recommended that a training system be developed to ensure all operators are knowledgeable and competent to operate the system. A competency based training system for the tele-remote systems was then implemented. The training consisted of an examination of Standard Operating Procedures for level access and other critical procedures, a physical examination of the operating environment, including a barrier check, level lockout, SCADA liaison, tele-remote chair pre-start operation of the LHD in tele-remote mode and practical assessment of the above tasks.

Swadling and Dudley (2004) present the training system requirements as being a system that would allow the evaluation of an operator's skill with criteria more selective than just speed. Consistent speed with no damage was the preferred situation. The use of the system was also to provide familiarisation with the tele-remote's controls and absence of physical feedback given during real tele-remote operation.

The simulator program emulates the functions of the tele-remote LHD and provides the operator visual feedback of the LHD in operation within the simulated mine. Operator performance is also recorded. The controls used by the operator are the same as the real LHD.

During operation a new operator record is added to the database each time the simulator runs and Swadling and Dudley (2004) comment that the information recorded includes, session duration, average speed of the LHD, buckets moved in the session, the total time that some part of the LHD scaped along the drive wall and the number of damage incidents in the session and an estimation of damage severity.

The benefits achieved from the training simulator are identified by Swadling and Dudley (2004) to be control familiarisation. The simulator was designed to utilise precisely the same controls as a real tele-remote LHD. The LHD manufacturer was impressed by the operator's ability to quickly adapt to the control of the LHD and initial productivity information supports this anecdotal evidence. VR Loader also gave LHD operators the opportunity to develop a feel for remote operation, which required operation without the usual sense of perspective and other sensory feedback gathered during manual operation.

In their analysis of the results achieved by VRLoader, Swadling and Dudley (2004) mine-site experience showed that operators that perform and produce well on VRLoader also perform and produce well under real tele-remote operating conditions. Swadling and Dudley (2004) found that as most operator's tele-remote hours increase, their tele-remote productivity approaches that recorded in the simulator and that this may appear to indicate that the simulation did not provide adequate training. However, Swadling and Dudley (2004) believe that there are two factors that would explain this result. The first was that there would be significant peer pressure to not damage the real LHD in real life and this was not present in the training sessions. The second was that the fidelity of the simulator did not reflect the individual differences between the LHD machines.

Swadling and Dudley (2004) conclude that the VRLoader was the first application of Thales to the mining industry and that at a first glance; the mining industry appears to be an ideal candidate for the technology. However, the use of simulators in the mining industry appears to be sporadic due to perception that it simulation does not fall into the core purpose of mining production and is not the only way to get things done safely.

The sporadic adoption of virtual reality simulator technology by the mining industry is still sporadic in 2009.

Mining Equipment Operation Simulation (2)

Schmid and Rossmann (2004) report that, Deutsche Montan Technologie GmbH (DMT) and Deutsche Steinkohle (DSK) have developed virtual reality (VR) technology to train mine workers and that virtual reality is a modern and intuitive way to provide faster and easier understanding and access to any information. They quote the proverb “I hear and I forget, I do and I understand” and that this proverb is a major motivation to use VR models for training.

According to Schmid and Rossmann (2004), creating realistic models of the working environment is the first stage of virtual reality development. The VR simulator presents a training environment in which operators can enhance their skills as well as learning risks and consequences of operator error and the importance of complying with safety requirements. Schmid and Rossmann (2004), report that virtual reality is often a photo-realistic simulation of real or planned working environments and the programming of high end graphical devices and technologies originally developed for the games sector makes this possible and hence VR models can be experienced in four dimensions – width, height, depth and time. Virtual reality also provides and interactive experience of machine movements and complex environments.

Schmid and Rossmann (2004) remark that immersion in the virtual world gives the user a much better understanding of the system and scenarios can be analysed from various camera positions that would not be possible in a real mine. The VR system developed by DMT and DSK provides sustained support for operations being carried out in confined areas and covers planning and development and also instruction and training and users can choose animated sequences or 3D-graphic displays when developing their own VR world. The VR software creates a virtual training environment in which trainees can operate drill jumbos, loading machines or continuous miners that take skill, system understanding and experience to control.

According to Schmid and Rossmann (2004), the background setting is an important aspect of the simulator program and restricted space and poor visibility make life very difficult for operators. Within the simulator the workplace environment is realistically portrayed and reproduced using the operator functions before full productivity is achieved and the VR simulator enables crews to acquire these skills. The training sessions can deliver routine and non routine training scenarios and various VR immersion levels ranging from PC monitors to 3D projection screens. The VR simulator contains pre-given items of machinery with the appropriate control unit replica. Figure 5 shows a drill jumbo where an operator can compare drilling productivity against best case drilling and the effect of proper drilling and blast performance can be studied more easily. The different actions performed in the simulator are stored by the program.

Five Month Roadway Development			Comparison for 100m Development	
Conventionally Trained	Trained with VR Simulator		Conventionally Trained	Trained with VR Simulator
146.4 m	326.3 m		100m	100m
3.671 Man Shifts	3.944 Man Shifts		4 cm/MS	8.3cm/MS
~ 350 Euros/MS	~ 350 Euros/MS		~350 Euros/MS	~350 Euros/MS
1.28 Million Euros	1.38 Million Euros		2.500MS	1.205 MS
8.776 Euros / m	4.230 Euros / m		875 Thousand Euros	4.22 Thousand Euro
Cost Benefit 4.545 Euro / m			Cost Benefit 453 Thousand Euro	

Table 2. Lower Personnel Costs (Eur/m)

Schmid and Rossmann (2004) report that DMT and DSK have developed a purpose built VR training room that comprises of a minimum of two networked simulators (Figure 5). The photo-realistic depiction of various machines operating in an environment allows the trainees to study and participate in an interactive man/machine process as part of a group. The simulator has tactile controls and force feedback to give the user a sense of what the virtual machine is actually doing. The simulation also utilises real machine sounds to depict the actions being performed by the machine. This approach leads to a better grasp of the overall system and allows each operator to perfect the handling skills required for the particular machine. The VR training room was developed for training a road heading crew of 80 people at a colliery in Germany. The training program was designed for novices and also experienced miners. An example of the implementation of the training program and where it fits into training is shown in Figure 6. The crews of three to five operators were exposed to the virtual machines during the training sessions as opposed to more traditional methods. After five months, the new road drivages crew had their performance monitored and this was compared with a conventional crew working with the same equipment under similar conditions a few months earlier in the roadway.

The performance of the two new operator crews compared and the crew that experienced virtual training performed much better. The back calculation and cost benefit is shown in Table 2 taking only personnel costs into account. DMT/DSK remark that Table 2 shows that the better performance of a VR trained crew paid back the investment in the VR training room very quickly (Schmid and Rossmann (2004)).

The DMT and DSK experience of implementing a VR training program shows that a considered and systematic approach to operator training through the introduction of VR simulator training at a colliery produced significant improvements in operator training. When this approach is considered on a cost basis, the improvement in production quickly recouped the cost of the implementation of the VR training room.

Figure 5 DMT, DSK Drill Rig Jumbo Simulator

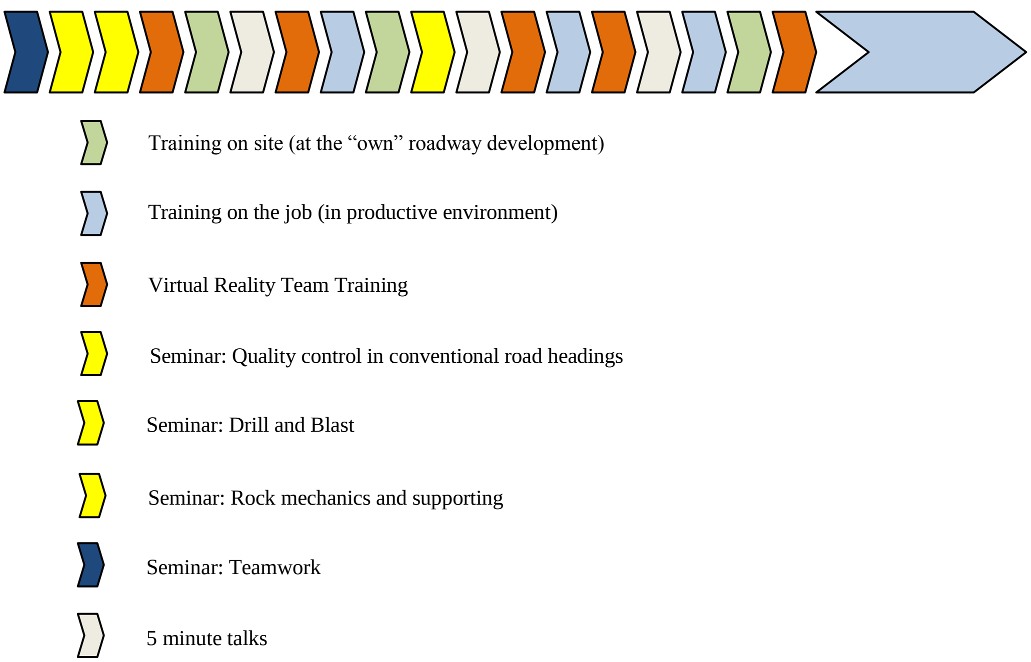

Figure 6: Road heading crew principle training schedule.

Mining VR Simulation: Usability - RSA

Van Wyk and Villiers (2008) considered the useability of the simulations developed for training South African Miners and state that The International Organisation for Standardisation defines usability as the “extent to which a product can be used by specific users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use” [ISO 1997].

Van Wyk and Villiers (2008) observed underground mine workers. 43 structured interviews were conducted and showed that the subjects had different cultural backgrounds and languages. Some have limited English; ages are between 20 and 60, education varied from grade 5 to grade 12. Mining experience varied from 2 to 25 years. Most underground workers were men. Interviewees were confident that they could perform their duties well. More than 80% had never used a computer and most were unafraid of using a computer and had the opinion they would enjoy it. Mine workers also indicated that they were concerned about safety arising from production bonuses offered.

Van Wyk and Villiers (2008) focussed on hazard recognition and identifying correct procedures in addressing hazards. Ground falls are the major cause of fatalities and it is essential that miners correctly identify geological conditions, especially after blasting. Generic workplace hazards generally also relate to support conditions, inadequate ground conditions, inadequate escape ways, fire, unsafe electrical connections, humans in proximity to loose rocks and working under unsafe roof and sidewalls.

Training is done in accordance with the unit standards as specified by the Mining Qualifications Authority. Most mines have training centres where training is class-based and instructor lead and in general the use of technology is limited. Some mines do have computer based facilities. Classroom training is usually followed by practical training and the instructor certifies the trainees as competent to perform work correctly and safely.

A prototype VR system was developed following interviews with mine managers and they found that a context of use analysis provided valuable information to inform the design concept. The outcome being that it was decided to place trainees in a 3D virtual underground environment where the haulage and stope areas would be realistically simulated and various generic hazards would be present. In the environment, the camera pans the scene and the user can stop the camera at anytime and identify a hazard. They must then remedy the hazard correctly. If the hazard is not remedied correctly, consequences are shown. The simulation is presented in several local languages as well as English.

Van Wyk and Villiers (2008) performed a usability analysis and since most trainees had not used a computer previously, a series of exercises was developed to teach them to use the computer. Once they were confident with the computer, Van Wyk and Villiers (2008) placed them in the simulator and they were marked for their ability to spot, identify and fix hazards. To evaluate user satisfaction of the prototype, an online questionnaire was completed by each of the participants. Van Wyk and Villiers (2008) found that,

- 87% of the participants indicated that they could easily identify all the objects in the simulated environment (high visibility).
- 93% found the system easy to use and understand.
- 95% indicated that using the prototype was an enjoyable experience.
- 84% indicated that they would prefer VR training to other types of training.

Van Wyk and Villiers (2008) further asked the participants if they thought the hazards in the prototype system could really happen and most felt that the hazards in the prototype portrayed real hazards in the working environment. A very interesting comment by Van Wyk and Villiers (2008) is that the trainees thought that most of the accidents could not happen to them.

The use of virtual reality of desktop and semi-immersive environments for training are considered by Van Wyk and Villiers (2008) to have application to the South African industry. However, more evaluation is required.

Mining VR Simulation: Hazard Spotting - RSA

In a more promotional paper, Van Wyk (2007) describes four systems developed for the South African mining industry. These were, Hazard Awareness, Interactive Simulated Geological Conditions, Accident Reconstruction Simulations, Trackless Mining Machinery and Hazards at Smelting Plants.

In the hazard awareness system a training system called “Look, Stop, Fix” was developed to focus on hazard recognition and remedial actions in underground working areas and incorporates potential hazards that mine workers need to identify and indicate possible actions that might be followed in each response to each hazard. Trainees must learn to spot these potentially hazardous conditions, identify the hazards correctly, and indicate which actions should be taken to address the situation.

In the simulation participants receive a score for each correctly identifies hazard as well as for correctly indicating the procedure to deal with each hazard. If the user does not correctly identify a hazard or the correct procedure for dealing with it, an animation plays out displaying the possible disastrous consequences. In the Interactive Simulated Geological Conditions simulation, geological conditions are simulated and trainees need to identify the condition correctly and the associated risks and control measures for each condition (Figure 7). During runtime the camera slowly moves through the virtual environment and the trainee is presented with a three-dimensional underground scene.

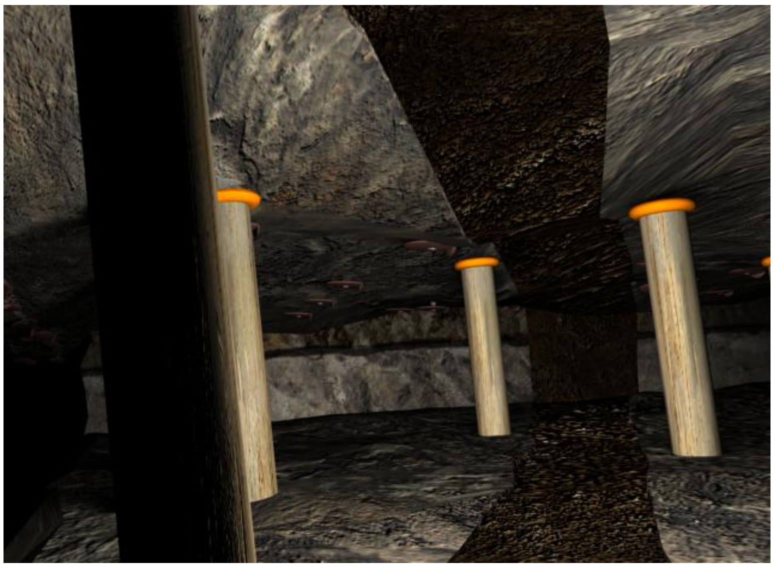

Figure 7. An incorrectly supported dyke condition After Van-Wyk (2008).

Van-Wyk presents some excellent examples of hazard spotting VR, however, the transfer and retention of experience gained in the simulator is not covered in this paper (it is a promotional paper so not unexpected).

A lot of effort has been placed on the realism for the simulation which is more than likely necessary for acceptance and for direct comparison to the workplace. However, it would be useful to have some indication of how users interact with the scene, what they learn and what information is transferred to the workplace.

Mining VR Simulation: University Mining Engineering Education

Kizil (2003) presents a paper on virtual reality and states that virtual reality is a continuously evolving computer technology that provides great opportunities for many industries including mining. Kizil (2003) comments that recent advances in virtual reality and the constant increase in the power of computers have allowed for the rapid expansion of VR applications and as the power of VR increase so too do its applications. Kizil (2003) considers that the most common human-computer interaction is computer generated visuals (visualisation), aural feedback, haptic and kinetic feedback, operator interaction devices and goes on to describe these devices in detail.

Kizil (2003) reports three different types of virtual reality systems; non immersion, full-immersion and semi-immersion. The non-immersion system is generally a desktop system with interaction devices such as keyboards, mice and joysticks. Full immersion systems refer to the use of head mounted displays and semi-immersion systems refer to projection systems and caves that partially or completely surround the user(s). In Kizil (2003) paper he refers to non-immersion PC systems and chose this format because these systems are relatively low cost and easily accessible to (University) students.

According to Kizil (2003), virtual reality is increasingly being used as an educational tool as a means to teach and train people without actually subjecting them to hazards and nowadays, computerised VR is used for education in many different fields, such as aviation, military, medical science engineering, research, mining and design planning. However, Kizil (2003) states that although VR should not be considered a substitute for real world training, it does allow for the reduction of the cost of training and improves safety. The use of VR in the initial training stages allows personnel to be taught to use equipment in a controlled and safe environment.

Kizil (2003) presents the advantages of using VR for education including, flexibility, inherently safe, wide application, intuitive interaction, motivating, interactivity, learn faster by doing rather than reading, people learn from mistakes, more efficient learning by enhanced sense of presence, students can get a better understanding of process. Kizil (2003) remarks that although the advantages of using VR are clear, there are important factors to be considered when producing educational VR. The first is to understand the strengths and weaknesses of VR, which should not be used to represent data already adequately shown in existing media types. The unique properties of VR should be utilised to provide a learning tool that would not be possible or as effective using other media.

Kizil (2003) proposes that teaching mining methods to students is a challenge for mining academics. The difficulty lies in representing 3D environments with 2D images and drawings. Kizil (2003) states that since the purpose of VR is to intuitively convey 3D concepts and environments through 3D graphics, it is an ideal solution to this problem. Under a project supported by the Minerals Council of Australia, a series of six modules was developed by Kizil (2003). These included block caving, open pit mining strip mining, longwall mining and sub-level stoping and cut and fill mining. Kizil (2003) believes that while the teaching modules that are developed will utilise traditional written text and graphics, it is the fully embedded 3D animations that will enable students to learn the design and production aspects of the featured mining method. While the authors concur broadly with this concept presented by Kizil (2003), it is unclear how this is measured.

Kizil (2003) also presents several other simulations including an Instron rock testing simulation, a Drill rig training simulator and a Barring Down simulator. Kizil (2003) developed the Instron Rock Testing simulation, the aim of which is to let students perform uniaxial compression tests on a number of rock samples. An advantage of this simulation is that students individually operate the equipment and perform tests as apposed to the more traditional approach of students observing a demonstration of the machine. From Kizil's (2003) description, it appears that the simulation is highly interactive for the student. The drill rig simulator developed by Kizil (2003) was developed to create a 3D model of a laboratory drill rig. The simulation includes the basic operating principles of the rig and some hazards that must be identified. Again the model is highly interactive and can be used for equipment inspection and operator training. The barring down simulation covers the serious issue of roof falls in underground mines. The system was developed to provide improved hazard identification training for underground workers primarily in relation to rock fall hazards. Kizil (2003) describes the main aims of the simulation as being to expose a trainee to various hazardous situations without actually risking their life. Taking the trainee through a mine and test their ability to do a risk assessment in hazardous situations and provide training in highly dangerous operation of scaling down rocks.

Kizil (2003) concludes that inadequate or insufficient training is often blamed for most mining fatalities. There is no doubt that the use of VR based training will reduce injuries and fatalities. However, justifying the use of VR in the minerals industry to improve safety is difficult to sell without hard evidence and quantified numbers.

Mining VR: Fire Escape Training - USA

Orr et al (2009) performed an informal study into VR training for mine workers in the United States to ask, "Can a VR system be used in a mine safety training environment to teach evacuation procedures, provide simulated experience and measure performance?" To address this question, an informal, preliminary test of the Virtual Reality Miner Safety Training (VRMST) software was performed. The software was developed in-house by the National Institute of Occupational Safety and Health (NIOSH) and was designed for mine workers to practice evacuation procedures. A preliminary test of this software was conducted during an eight hour, MSHA approved training course.

Orr et al (2009) based their software on the Unreal game engine and included custom maps, models and animations and comments that by re-purposing the computer game, the end user doesn't see any elements of the original game on the screen. The software provides a first person perspective on the virtual environment and Orr et al (2009) report that their simulation software uses a computer network to place four trainees within the same simulated environment and each trainee is represented by a computer-generated character. While in the simulation, trainees have independent control over their character in the virtual mine. First person simulation attempts to provide a virtual "first-hand" perspective of the setting.

The virtual mine setting is a common set-up in underground longwall coal mining and there are limited options for escape and according to Orr et al (2009) miners can easily become confused about which escape route to take. The simulated evacuation scenario reported was based on an actual incident involving a fire at a co-operating mine and included smoke that significantly obscures the trainee's VR vision in some areas. In addition, falls of ground caused by the fire and blocked the trainee's primary escape route and forced them to find an alternate path. Trainees were also presented with VR obstacles that required them to consider alternative escape routes. Orr et al (2009), remark that critical decision-making takes time and requires that trainees analyse their virtual experience. They must also communicate via telephone if the computers are connected from a remote location.

In their informal analysis Orr et al (2009) exposed thirty-two trainees working in four groups to test the simulation. Unfortunately they did not collect detailed demographic data from the subjects, however all the participants were experienced mine safety professionals and none had any significant experience in playing first-person video games. A 10 minute practice session was allowed to acquaint the users with the keyboard and mouse control of their character. During the practise Orr et al (2009) report that the users were also instructed to take note of specific landmarks and items that would be helpful in finding their way out of the virtual mine. Prior to commencing the simulation trainees were provided with the evacuation plan for their virtual mine that included preferred escape routes and a checklist of things to do as they evacuate.

Two scenarios were created by Orr et al (2009) the second being more complex than the first. The first scenario required the trainees to double back after finding a fall of ground and find the next in-bye man-door allowing them to switch to the second escape way. The second scenario required the trainees to alter their escape route more often with blockages in both the primary and secondary escape-ways. The second scenario required them to eventually find their way to the belt entry as the only means of negotiating the fire. The complexity of the second scenario makes it more likely that the trainees would become lost.

The experiment performed by Orr et al (2009) exposed half of the four person groups to the easier simulation first followed by the more difficult one. The second half of the four person groups were exposed to the more difficult scenario first followed by the easier one. Orr et al (2009) recorded the time taken in each instance and post-training interviews were held to collect individual trainees' reaction to the VR training medium.

Following their experiment Orr et al (2009) found that the VR evacuation training was successfully integrated into the eight-hour annual safety training refresher course. The four groups given the simple escape route first were found to complete the more complex scenario 37% quicker than the group exposed to the complex scenario first. No difference in completion time was recorded for the groups to complete the simpler scenario regardless of whether it was administered first or second. Orr et al (2009) report that the 'solution time' for the simpler scenario was about one-third of that recorded for each of the groups – "meaning that someone who is proficient with the software controls and had advanced knowledge of the proper path around the blockages could complete the task in less time. Orr et al (2009) conclude that these factors indicate that the improved performance was a result of the VR experience and not from increased proficiency with the software.

Orr et al (2009) remark that trainees felt that the training was effective and that they felt more prepared to follow an evacuation plan as a result of the VR training although Orr et al (2009) concede that this would have to be compared to a control group exposed to more traditional training to draw significant conclusions.

In their discussion, Orr et al (2009) comment that the preliminary testing of the VR software indicated that trainees increased their ability to escape from a virtual mine fire and that it is hoped that this would translate into an increased ability to escape from a similar situation in a real mine evacuation, however, Orr et al (2009) are aware that more elaborate testing would be required. During their experiment, there was also evidence that previous trainings that miners had received were applicable in the VR world. Six of the eight groups stayed together in the virtual environment, as instructed and waited for another if separated. These groups also followed the evacuation procedure checklist, as instructed at the beginning of training sessions. One group chose to follow a leader who did not know how to navigate in an underground mine. Orr et al (2009) conclude that because it is difficult to provide hands on training for mine-disaster situations, VR simulations can provide an opportunity for miners to be exposed to realistic situations without endangering their lives.

Orr et al's (2009) approach has application o remote mining situations.

Mining VR: Conveyor Belt Safety - USA

Lucas et al (2007) have developed a virtual reality simulator to improve conveyor belt safety in surface mining and suggest that VR offers the opportunity to immerse the user into a computer generated reality which is too dangerous, difficult, or expensive to play in real life. The driver for the development was serious injuries and fatalities that occur around conveyor belts because of apparent inadequate training.

Lucas et al (2007) report two project phases. The first develops an instructional-based module. The second involves task based training. Problem based simulation scenarios were planned to test the user's ability to identify and remedy risks while immersed in the virtual environment. Task related information can be accessed from within the simulation. According to Lucas et al (2007), the trainee's ability to identify and remedy risks can be quantified and the consequences of poor decision within the environment can be demonstrated. This allows for enhancing the cognitive learning process of users after both modules are completed although it is not clear how this occurs.

The accident statistics for conveyors show that no matter how innovative, sophisticated, specialised, or foolproof the safety technology, its long term performance is governed by the human element and hence the number of fatalities caused by conveyors and reported by Lucas et al (2007) in their paper reaches almost 50. The serious injuries are in the hundreds.

Current training is the responsibility of the owner/operator of the mining facility. Common practise is for basic safety awareness to be incorporated into videos and slide shows. With the lack of developed training programs, conveyor belt training is left to on the job training where a new employee is placed with experienced personnel to learn the operation and maintenance. Lucas et al (2007) comment that a downfall of on the job training is that is cannot be quantified and checked for adequacy, it also allows for inexperienced people to be exposed to the dangers of a conveyor system.

The instructional based module prototype was designed to familiarise the trainee with the working environment around the conveyor belt, its components and alert them to the related hazards of the moving components. The module presents the user with two options for navigating the virtual environment - an automated walk-through or a manual walk-through. The 3D digital conveyor is based on images taken from site visits to cement production plants, reference to an engineering foundations book and a guide to equipment guarding. The model includes several conveyor systems. Hotpoints in the model are identified by flashing icons and are colour coded to indicate different types of information including belt assemblies and components, possible hazards and safety issues.

Lucas et al (2007) report that the instructional based prototype is intended to give the user the needed information so that they would be able to complete tasks safely and recognise and fix hazards in the work environment. It was a goal of this phase of research to prepare the trainees to complete tasks safely in the working environment and have the capacity to recognise dangers and fix them properly. Lucas et al (2007) comment that the information presented will be reviewed by industry professionals and training specialists for completeness and accuracy and once a trainee completes one or more sessions of the information module, their learning ability will be tested in the task-based module sessions.

In their evaluation Lucas et al (2007) planned to perform two types of evaluation on both phases of the proposed safety program. The first was an informal evaluation performed using 2 or 3 field safety officers. These people will review the instructional based information. The second evaluation was planned to be through the use of human subjects. Lucas et al (2007) present an experiment where one test group will sit through a standard safety training session of videos slides etc, while a second group of similar size sits through an instructional based VR module. Both groups would then be tested using the task based module that was yet to be developed. Lucas et al (2007) present no results in this paper.

The conclusions that can be drawn from Lucas et al's (2007) paper are that a conveyor belt simulator was developed logically and systematically. The consideration of instructional design is encouraging. The lack of real field results in this paper is a concern.

Mining VR: Task-Based Training Tool Conveyor Belt Safety - USA

Lucas and Thabet (2008) present a second paper on VR task-based training for conveyor belt safety. The required training for new hires to the mining industry in the United States is reported to be 24 hours. 4 hours must be undertaken prior to commencing work and the remaining 20 hours must be administered over the next 60 days. Formally documented training is required by the industry and every miner must under go 8 hours of refresher training per year. Lucas and Thabet (2008) comment that there is a need for a structured training program and that the guidelines for training appear inadequate. The training procedures themselves are also inadequately addressed and owners and operators are left to fulfil requirements.

Current training programs are lecture-based and are dependent on slides and video presentations to convey safety guidelines and procedures and Lucas and Thabet (2008) believe that training methods are not sufficient for the wide variety of learning styles and educational levels that exist in the mining industry. Also, a younger demographic of mine workers may learn from computer applications whereas the older demographic may learn best from traditional methods. Regardless, Lucas and Thabet (2008) state that all adults often learn from an active, experience based approach. Current training practices do not accommodate the wide variety of learning styles available in the industry and most are passive in nature. Lucas and Thabet (2008) suggest that knowledge learned from typical training methods is done so without the trainee reflecting upon and experiencing the information. To enhance the learning the material must be tested in new situations by the trainee. Consequences of actions are also not experienced at all due to the fact that the real environment would not allow the trainee to perform ‘what-if’ scenarios.

Lucas and Thabet (2008) believe that on the job training has value as an active experience based approach but does not allow the participant to make mistakes as the consequences can be very severe. Poorly planned on the job training can also inhibit proper performance and cause a rise in injuries. A developed VR application can ensure adequate training and offer the experience of consequences.

Lucas and Thabet (2008) propose that virtual reality applications can ensure adequate training and offer the experience of consequences. Virtual reality also offers the potential for a reduction in injuries and fatalities through representation of real-life events in an artificial environment. They also propose that virtual reality offers cognitive learning methods for trainees to think through actions needed to complete tasks. Trainees can come into contact with the consequences of their actions and receive immediate feedback. In virtual reality the user has control over the environment and can play out tasks and they are more likely to be able to perform those tasks in real life safety situations.

During the virtual reality simulation Lucas and Thabet (2008) propose that the user’s performance can be tracked and that cognitive learning experience places interest in the virtual reality simulation for task based learning. In their virtual reality training module design, Lucas and Thabet (2008) identify a four step program for developing the training program for conveyor belts. This process is shown in Table 3.

Lucas and Thabet (2008) performed several site visits and identified some specific areas of training for the virtual reality training system. A prototype was proposed that consisted of two modules, an instructional module and a task based module. The instructional module was developed to introduce the data. The task based module then tests the knowledge of the user to help determine the user’s skill level. The prototype application was evaluated upon completion to ensure that it met industry needs and was perceived as an effective way of learning material.

Step 1. Data collection • Site visits • Literature review	Step 1 includes the initial collection of data. This was done through site visits with taking pictures and interviews. Literature review was also conducted to find current practices, requirements and accident statistics.
Step 2. Define Training Areas • Information about conveyors and components • Possible hazards. • General practices. • 2.4 Skill testing method.	Step 2 takes the information that was collected in step 1 and categorises it to be used and distributed in the Instructional Based Module
Step 3. VR Prototype Implementation • Instructional-based Module • Task-based Module	The information is distributed to the user in the Instructional based Module and the user is tested on that information during the Task-based Module where their performance is tracked and scored.
Step 4. Evaluation and Feedback • Useability evaluation • Subjective Analysis (Potential usefulness study) • Performance based comparison.	The entire system is put through a series of evaluations to ensure that the information presented is accurate, that the interface is useable and to test the advantage of using a VR system over traditional methods of training.

Table 3. Four steps to safety training program structure. (After Lucas and Thabet (2008))

Lucas and Thabet (2008) state their goal as being to create an effective method for safety training professionals to efficiently train new younger miners and ultimately reduce injuries. In addition to the testing and evaluation of the prototype PC based application the application was ported to an immersive CAVE environment.

In their discussion, Lucas and Thabet (2008) comment that recently, training has evolved from traditional classroom training to computer based training in many fields and that classroom training is utilised because of the knowledge that a quality training professional can instil in trainees during classroom sessions. Computer based training has become more popular because it is believed to enhance the cognitive learning of the user. Cognitive learning being the process of acquiring knowledge and understanding through thought experience and the senses.

Lucas and Thabet (2008) discuss several theories of cognitive learning and propose that these can be applied to their virtual reality training system. While navigating within a virtual reality environment the user goes through a series of training (instructional based sessions) and rehearsals (task based training) and unlike traditional slide show methods and videos it is an active learning experience where the user is in control. According to cognitive theory, the actions and reactions as the user proceeds through the system are placed in working memory until they are encoded with similar information in the long-term memory. When the user comes across a real-life situation the appropriate knowledge is retrieved from long-term memory where the user would also know the consequences of mishandling the situation.

According to Lucas and Thabet (2008) cognitive learning theory research has shown that computer based training application can enhance the training process and give the trainees a better understanding of the material when it is interactive in nature. The task-based prototype developed uses the model of cognitive theory for training new miners and testa their knowledge and skill level of the information distributed. Each exercise in the module is designed using a five-part framework that evolves around instructional design theory- the ADDIE (Analyse, Design, Develop, Implement and Evaluate) model.

The prototype reported by Lucas and Thabet (2008) also takes advantage of a more advanced instructional model that revolves around the user's needs and their critique and feedback. The module development also included industry personnel at various steps to ensure that the module fits into industry training needs.

The five step framework presented by Lucas and Thabet (2008) includes the following steps,

- Determine the skills to test.
- Define the training scenarios.
- Determine consequences and rewards.
- Animation and programming.
- Testing of quality assurance.

The above are approached systematically by Lucas and Thabet (2008) and covered in detail in their paper.

Lucas and Thabet (2008) performed some basic evaluation via a series of studies to ensure that the application would fit the needs of the industry. A useability evaluation and a usefulness study were performed and a performance based comparison was planned for future research. Some key issues were identified by Lucas and Thabet (2008) in that instructions given at the beginning of the sessions were difficult for people to remember and the objectives were unclear. Navigation within the model was also a problem to most participants. The usefulness study was designed to capture the participant perceptions of the advantages and shortcomings of virtual reality simulation. The numbers in the study were low at eight. Five out of the eight did prefer the virtual reality learning because of the interactive experience and users were able to view progress step by step. They also felt that interaction gives them control.

Lucas and Thabet (2008) conclude that the aim of the developed prototype was to examine the potential usefulness and effectiveness of a virtual reality safety training application for surface conveyors. A goal was to effectively train an incoming phase of younger miners. Some issues with usability and instruction were identified and navigational controls were found to be a problem. The true effectiveness of the virtual reality training could not be established until a performance based evaluation is performed.

Medical VR: Medical Procedure

Aggarwal et al (2006) discuss the use of a virtual reality training program for surgeons where the implementation of a competency based surgical skills curriculum necessitates the development of tools to enable structured training with in built objective measures of assessment. Simulation in the form of virtual reality and synthetic models was proposed for technical skills training early in the learning cycle. Aggarwal et al (2006) considers that for the training to be efficacious, these tools must convey a sense of realism and a degree of standardisation to enable graded acquisition of technical skills. Progression along the curriculum is charted by passing predefined expert benchmark criteria that lead to more technically demanding tasks.

Laparoscopic surgery is reported by Aggarwal et al (2006) to have previously been performed on inanimate video trainers and latterly on virtual reality trainers with shown improvements in skills in the operating room. However, structured training programs using these tools do not exist and have not been validated.

The aim of Aggarwal et al's (2006) work was to develop an evidence-based virtual reality training program for the initial acquisition of technical skill and a base level of proficiency prior to entering the operating theatre. In virtual reality, basic and procedural tasks can be simulated in a high fidelity virtual environment that closely represents the operative field. Virtual tissues can be manipulated, clipped, cut and incorporated into a dissection that can bleed and respond to diathermy. At the end of each task, performance can be measured and using parameters such as time taken, path of the hands, number of errors made making it possible to chart the performance and proficiency of trainee surgeons.

Aggarwal et al (2006) remark that a structured curriculum can enable trainees to be confident in their skills prior to assisting in and performing procedures in the knowledge that they have achieved preset expert criteria. The ultimate aim is for them to reduce their learning curve on real patients.

Aggarwal et al (2006) recruited 40 participants, 20 of whom were experienced laparoscopic surgeons and 20 were novices. The surgeons were exposed to a controlled experiment on the laparoscopic simulator that had differing levels of complexity that could be selected at runtime.

Aggarwal et al (2006) report that to ensure the acquisition of skills, repeated practice must lead to the improvement in performance of trainees and plateau towards that of an experienced surgeon. The preset expert criteria to achieve can be defined by analysing the scores of a pool of experienced laparoscopic surgeons on the simulator. The settings of the simulator were considered carefully by Aggarwal et al (2006) to ensure their validity and that they lead to improved technical skill. The performance of the two groups was analysed and revealed a median of seven repetitions to show an improvement in novices and a second repetition for experienced surgeons.

In their detailed discussion, Aggarwal et al (2006) state that a competency based training curriculum for laparoscopic surgery must use valid tools that enable the trainee to practice on a series of standardised technical tasks. Pre-defined benchmark criteria can ensure that skills acquisition has been successful. The results of Aggarwal et al (2006) study have defined a model for training on a particular simulator that then become one of the components of a competency based training curriculum – in this case laparoscopic surgery. Data have shown that several sessions at increasing levels of complexity is the most appropriate method for this type of training. Following this impressive scientific experiment, Aggarwal et al (2006) hypothesise that a proficiency based VR curriculum will improve the performance of junior residents when operating on real patients.

Aggarwal et al (2006) presented a very informative study on how virtual reality training in surgical operations can improve the technical skills of junior surgeons. Having junior surgeons perform multiple levels of simulation and repetitive sessions allowed them to acquire the necessary skills. These sessions were delineated by an hour so that multiple sessions could be performed in one day and each time the difficulty level increased.

This approach may be appropriate for mine training using simulators so that trainees are exposed to simulations that allow them to build confidence through interaction with the simulator.

Literature Review Discussion

The volume of literature available for review via the Internet and more importantly in electronic journals and conference proceedings is massive and the examples and case studies presented here have shown in some detail that virtual reality training has been implemented in several industries and has been developed for mining applications.

The idea of using games based technology for simulation and training in mining applications has been in existence for well over a decade and was considered in the early stage of development as a mechanism to make virtual reality training available to all levels of industry. Since this idea was conceived, there have been cases of simulation technology and models being delivered to industry all over the world and also being developed for training and education from mine-site training through to University level mining education.

All of the simulators presented have used 3D models to present information and many have incorporated video and photographs to enhance the simulation. Some simulations have tactile machine controls implemented and most have a navigation and interaction device available for the user to interact with the image. Access to web based textural information is also possible.

In some cases the course design within the simulations has been considered in details and the primary instructional content developed as an educational tool to compliment a secondary implementation component where learned information is practices and applied. Where the virtual reality simulation fits into the training and education process has been considered by several authors and virtual reality seems well suited to team environments. Where the simulation fits into the training process and what it must deliver also need serious consideration. The literature relating to the formal educational evaluation of the Working at heights module is dealt with later in this report.

Much attention has been placed on the level of realism required in the simulations due to the need to give trainees a ‘real’ experience and also provide as realistic experience as possible. Many of the simulations aim to prove a sense of presence when the user is immersed in the simulation from the perspective of giving as real an experience as possible.

The usability of the systems has been considered in some instances and is a very important aspect of simulation as the controls for the environment should be a transparent as possible and not detract from the core purpose of the simulation which is to train people in a task or process.

Many of the simulations have been developed from the aspect that the scenarios and processes that that they portray are extremely high risk and if experienced in real life would cause injury or death to the trainee. The idea is that the user can experience the consequences of bad decision making without suffering the consequences and hence learn from that mistake.

This concept is OK, but the core idea should be that the instructional design within the simulation should allow people to work in an environment in a safe manner and avoid adverse conditions – they may only need to be made aware of the consequences and not necessarily shown them. There is a danger of desensitising people.

If people are working in a situation where a severe risk or consequence could arise, that risk should be removed completely or the task substituted for lower risk solution. Identifying a hazard and selecting a remedy according to rules and procedures is not really a solution and the hazard itself should be removed though engineering practices. Be made aware of those potentially hazardous situations in context is one of the powers of simulation. It may be that it is those practices that should be modelled and assessed in virtual reality simulation with the intention of identifying where people should be removed from such risky environments as much as possible.

Many of the simulations are derived from training materials and try to replicate complex rules and procedures. It is the complexity of these procedures themselves that may cause overload of the user's working memory. Introducing too many issues at once can potentially have an adverse and if the material is too complex or too simple for the intended user, then this too may reduce the effectiveness of the simulation.

The intricacy and fidelity of the simulations also needs to be considered and as in the case of medical simulations where the level of detail, pre-knowledge and assessment all play a part in the simulation. This ensures that a level of competency is attained on the simulator prior to the users experiencing reality. In these situations, user feels more confident to perform their duties after practicing on the simulator.

Finally, the literature review shows that pretty well any type of simulator can be built and to a very high standard of resolution and fidelity which are important more for acceptance than educational value. Why build a low resolution-low fidelity simulation nowadays when there are numerous tools available to build high quality ones, for not a great deal more investment. The benchmark that is used by the public and hence miners is the modern computer games industry and the quality of graphics that it presents. However, the development of interaction, the design of the scenario and the methods of assessment must all compliment the existing training tools and where possible replace the ‘traditional’ methods where appropriate to ensure that there is a consistency of information presented to the user.

The involvement of the end user and trainer’s in the development of the simulations is essential because as they become more confident with the technology, they will develop innovative uses for the simulation and add value to its development.

Trainer’s and educators are also valuable pools of experience and anecdote that bring the simulation experience to life and make this more engaging for the user. Humans prefer to socially interact with humans and hence any simulation should ideally include an opportunity to work with others as a shared experience while they are immersed within the simulation – whether it is a desktop based simulation in a classroom environment or a group based simulation in a large screen immersive environment.

5. Game Engine Review

The purpose of this review is to recommend current game engine technologies for use in future BHPB ODX Collaborative Projects while also taking into consideration the development that has taken place so far with Virtools. Virtools was already being used as the rapid prototype development facility provided by UNSW School of Mining Engineering under the project.

Under the review, criteria for an ideal game engine were first defined and then used to investigate a variety of game engines for suitability in developing VR simulation modules. Engines were also categorised as either, Open Source, Commercial or AAA based on cost and features. The most suitable engines in each category were then identified and evaluated.

In their respective categories, Unreal Engine was identified as the most suitable AAA engine, Virtools was identified as the most suitable commercial engine and OGRE was the most suitable Open Source engine.

Virtools was originally chosen as the game engine package used to develop modules. However, due to a change in direction and development circumstances of the BHPB ODX Collaborative Project, OGRE has emerged as a viable alternative to Virtools.

The core software components of a game, simulation or other real-time graphical application are referred to as the game engine. The tasks that these components are responsible for include graphics rendering, audio, physics simulation, networking, command scripting, artificial intelligence, animation, and scene management. Use of a game engine simplifies simulation development and can shorten the production process significantly. A game engine allows developers to focus on content creation rather than the underlying framework.

Choosing the right game engine is essential for the success of a simulation project. It is a long term investment that will determine the cost and development time of future projects. For the BHPB ODX Collaborative Project, a number of game engines were evaluated based on their component functionality and production costs. This report details the evaluation criteria and processes used to determine the ideal game engine as well as recommending engines that are most suitable.

Previous development work

The current Working at Heights module was developed using Virtools over the period of the project. Virtools was chosen as the authoring package/game engine after a review of current game engine technologies available at the end of 2008. That review concluded that Virtools was the best choice for development due to its rapid application development capabilities, the existing compatibility with the AVIE screen system, the development team's experience with using the software and the time constraints associated with the module development.

The Working At Heights module was a prototype created under specifications that were subject to iterative changes. These conditions are ideal for using a rapid prototyping or rapid application development approach towards creating the module, adding further weight to the Virtools decision. Now that the Working At Heights module has been completed, specifications can be drawn up with a better idea of what can be achieved. The original specification included the possibility for module deployment on the AVIE system, as well as a standalone system. Given these constraints, the best game engine to use for module development was Virtools due to its scalability across the mentioned platforms.

The experience gained from this development with Virtools was taken into account in selecting an ideal game engine for future modules to be created for the BHPB ODX Collaborative Project.

For reference, the programming interfaces are shown in Figure 8 and 9.

Procedure

Eves and Meehan (2009) reported that there potentially hundreds of game engines available on the market as of the writing of this report. An initial scope of available game engines was conducted to narrow down the choices. A detailed comparison chart was then created to compare each engine's specifications. This chart is shown in Appendix and a sample is shown in Figure 10. The engines were then placed into three categories: Open Source, Commercial and AAA based on the results.

Open source game engines are designed and developed under an "open" ideology; the source code is made fully available, and the engines are often developed in a public and collaborative process. The restrictions placed on the use, modification and redistribution of an open source engine are covered by its license. Open source engines can range in functionality from providing a simple framework to complete engine component implementations with additional tools to assist production.

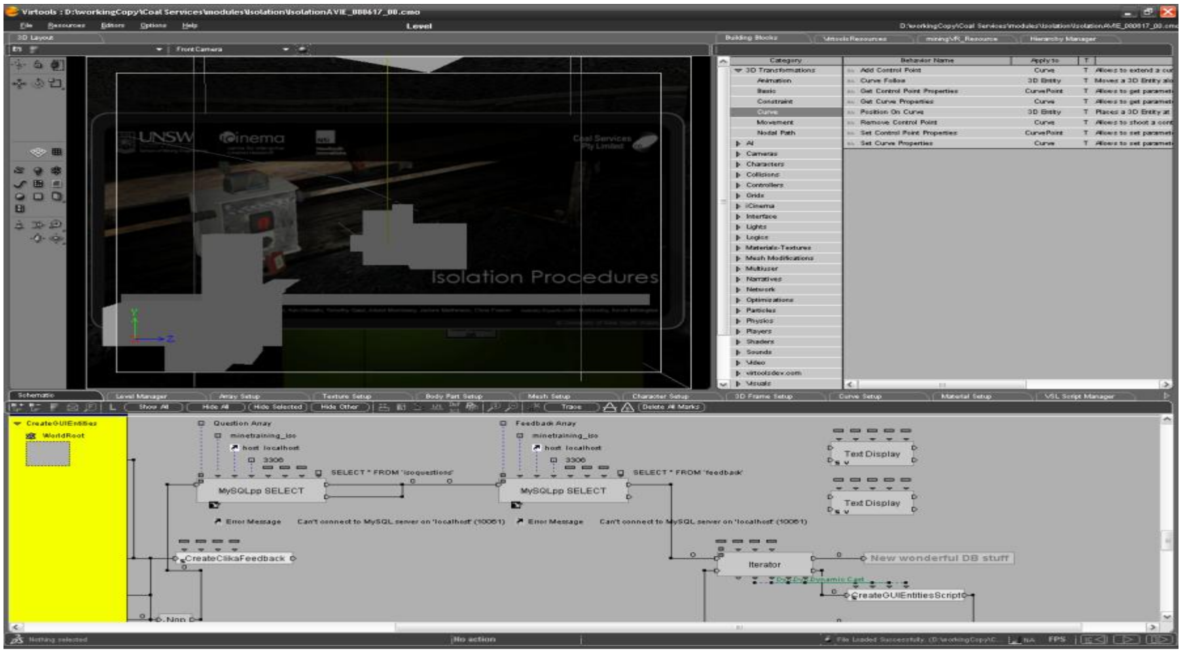

Figure 8. Example Virtools rapid prototyping interface.

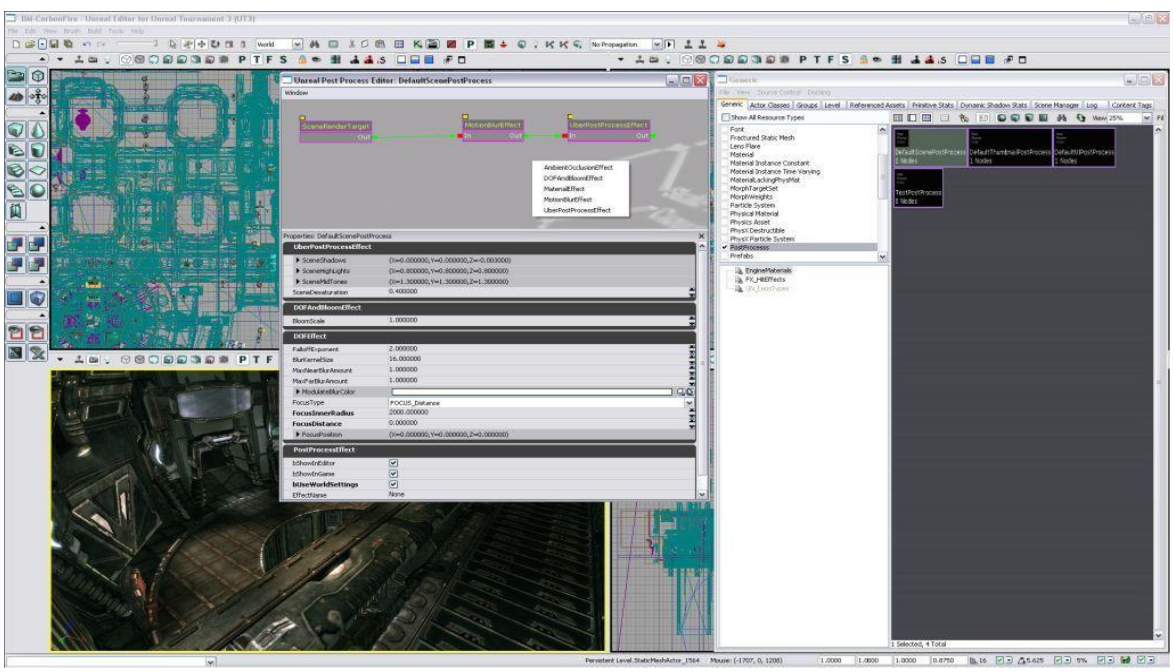

Figure 9. Example Unreal prototyping interface.

Commercial game engines are off-the-shelf application suites that can be purchased or licensed for as little as $80 or up to several thousands of dollars. These engines are usually 'closed source', which means that the source code of the engine itself is unmodifiable by users. In the cases which the source is modifiable, a considerable license fee is usually required for developers to be able to edit the source code.

Engine	Type	Company	OS	3D Support	Map Channel Support	Vertex Colour Support	Multiple Materials per Mesh	Graphics API
Quest 3D	Commercial	Act-3D B.V. http://www.quest3d.com/	Windows	Max exporter COLLADA .X (DirectX) .3ds	3, (2 for .X format)	Yes	Yes	DirectX
Unity	Commercial	Unity Technologies http://unity3d.com/	Windows (some limitations), MacOS	Maya (.ma, mb) Cinema 4D (.c4d) Cheetah3D (.jas) Blender (.blend) .FBX	Multiple	1	Yes	OpenGL, DirectX
Torque	Commercial	GarageGames http://www.garagegames.com/products/torque/tge/	Windows	Max exporter Maya exporter	1		Yes, but not efficiently. Shader workaround possible.	DirectX
Virtools	Commercial	Dassault Systèmes http://www.virtools.com/	Windows MacOS	Max exporter Maya exporter COLLADA supported in Virtools 4	8	1	Yes	OpenGL, DirectX
C4 Engine	Commercial	Terathon http://www.terathon.com/c4engine/index.php	Windows MacOS	Max exporter (COLLADA) Maya exporter (COLLADA)	Multiple	Multiple	Yes	DirectX
Game Studio A7	Commercial	Conitec Datensysteme GmbH http://www.3dgamestudio.com/	Windows	Maya Exporter (commercial) Max <= 6 Exporter (commercial) .FBX	Multiple	A6 didn't support Vertex Colours. Not sure about A7	Yes	DirectX
Vred	Commercial	VREC GmbH http://vred.org/	Windows Linux	Maya Exporter VRML FHS STL				OpenGL
ID Tech 4	Big Budget Games	ID Software http://www.idsoftware.com/business/idtech4/	Windows MacOS	Max exporter Maya exporter	Multiple	Multiple	Yes	
Unreal Engine 3	Big Budget Games	Epic Games	Windows MacOS Linux	Max exporter Maya exporter COLLADA	Multiple	Multiple	Yes	OpenGL, DirectX
CryENGINE 2	Big Budget Games	Crytek GmbH http://www.cryengine2.com/		Max exporter Maya exporter	Multiple	Multiple	Yes	
Source Engine	Big Budget Games	Valve http://source.valvesoftware.com/	Windows	Max exporter Maya exporter	Multiple	Multiple	Yes	DirectX
Panda 3D	Open Source	Carnegie Mellon http://panda3d.org/	Windows Linux	Max exporter Maya exporter	1	1	No, would require multiple exports	OpenGL, Cg, DirectX in development
		Steve Streeting	Windows	Max exporter				OpenGL

Figure 10 Excerpt of the Game Engine comparison chart. (Refer Appendix).

AAA game engines are commercial game engines with complete component functionality, additional toolsets to assist the production process and noteworthy commercial success. The licensing fees for AAA engines range from between $10,000 to several hundreds of thousands of dollars and are often accompanied by royalty agreements.

The game engines reviewed were divided into the aforementioned categories and ranked based on how they met the requirements for a VR simulation. The most suitable engines in each category were evaluated further.

In the next stage, various models were used to test the integration of 3D assets in each game engine. They were exported from 3D Studio Max or Maya to the game engine using the exporter available.

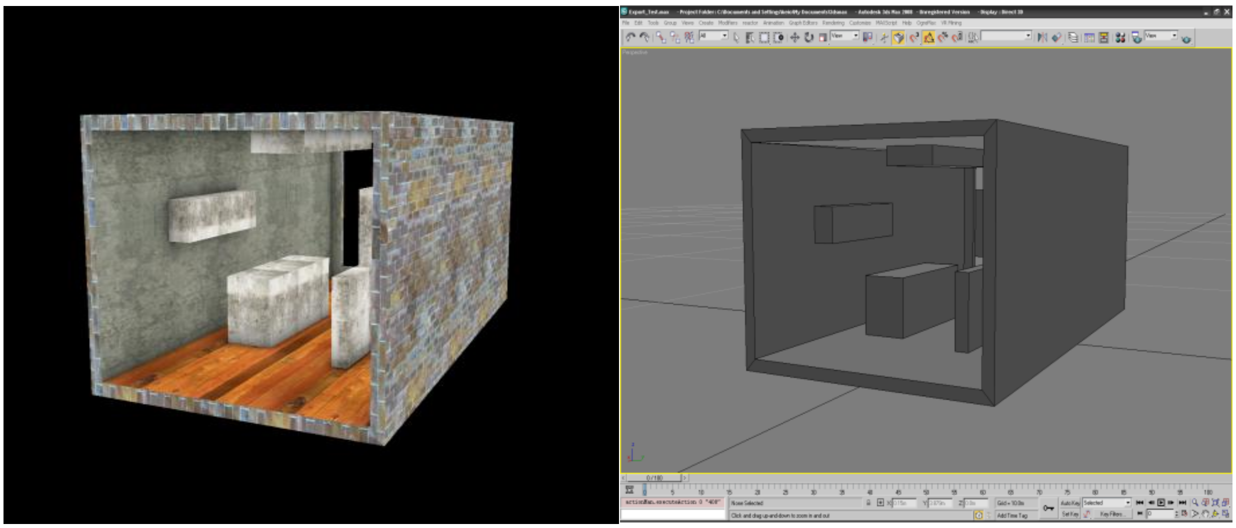

Figure 11a) Rendered test scene in OGRE. b) Editing view of test scene in 3D Studio Max

The first scene shown in Figure 11a and b contained the following:

- UV channels per vertex - two sets of different texture coordinate data stored at each 'point' on the 3D object
- Vertex colours - lighting information stored at each vertex
- Multiple materials per mesh - more than one set of material information per 3D object
- Diffuse + Lightmap - two sets of texture maps to approximate diffuse lighting and ambient lighting on a 3D object

These were the minimum features of a scene that the game engine should support. Any exporter that was not able to export all of these aspects of the scene successfully was noted. Once the scene was exported, a small program/script was written in the relevant game engine code to import the scene and be able to navigate around in it. The steps required to do this were noted during the process. The amount of documentation needed to be viewed as well as such documentation's availability was also noted. The success of importing a scene in a particular game engine was recorded.

For the engines able to successfully import the scene and walk around in it, the performance of the engine was noted, in terms of frame-rate.

In addition to this test, a list of pros and cons was made for each engine, highlighting the best features and shortcomings that were relevant to the feature requirements.

All these results were tabulated for comparison and are shown in Appendix.

Required Features of a Game Engine for Mining VR Simulations

Based on experience from previous and current VR simulation development, a list of features that an ideal game engine should have was constructed. Each game engine reviewed was evaluated based upon how well it could meet the feature requirements. These are as follows:

- Prototyping/Rapid Application Development.
- Smooth integration of 3D assets.
- Ability to customise graphics pipeline using Shader languages (HLSL, GLSL, CG, etc).
- Support multi-user simulations.
- Support web deployment.
- Allows collaboration between developers.
- Reasonable cost and licensing agreement.
- Ability to run across a cluster of computers and/or a non-standard display.
- Product support/community size.

Prototyping/Rapid Application Development

The Virtools authoring package that was used for past and current VR simulation development allowed for rapid prototyping of modules within a few weeks of commencing work. This was beneficial for the small development team, as well as suiting the research-oriented nature of the VR simulation project, which was characterised by ‘ever-changing’ specifications (Figure 12). Improvements to the module were made iteratively, building upon previous code as required when the specifications changed. The Working at Heights module was developed using this methodology, with positive results in terms of time required and quality of the end result.

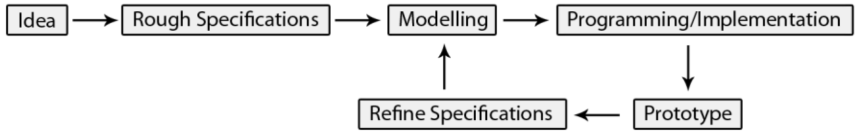

Figure 12. Development Process for VR Mining Simulations

One way in which a game engine could provide for easy prototyping or rapid application development is to have a scripting system to take care of actions and events within a program. Game engines usually have support for scripting languages as a means to increase productivity.

A scripting language is a programming language that can be 'interpreted' line by line without having to be compiled before executing it. When used in game engines, it allows actions and events to be programmed by calling on lower level functions of the engine. While this approach may not be as fast as programming each action and event in compiled code, the flexibility to be able to alter the scripts independently of the rest of the game engine easily makes up for the slight performance decrease. Some engines allow scripts to be run without having to restart the simulation. This is preferable to the alternative of 'hard-coding' all actions and events as it makes it easier to change what occurs in a simulation.

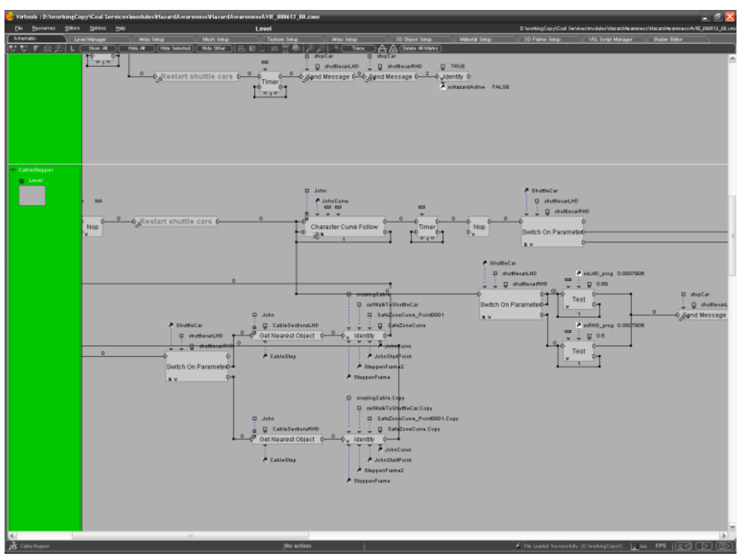

Figure 13. Screenshot of Virtools development environment

The ideal game engine must have support for a scripting language, preferably a commonly used scripting language such as Python or Lua, or a well-defined third party language, like Virtools' schematic scripting and VSL, or Unreal's Kismet. This will allow for rapid application development and reduce the amount of development actually required. An example of this type of development environment is shown in Figure 13.

Having a scripting framework that can be augmented will also save having to 'reinvent the wheel'. Since certain functionality would already be present in a scripting language (e.g. Virtools' messaging system) and developers can make use of this and design scripts capitalising on this feature.

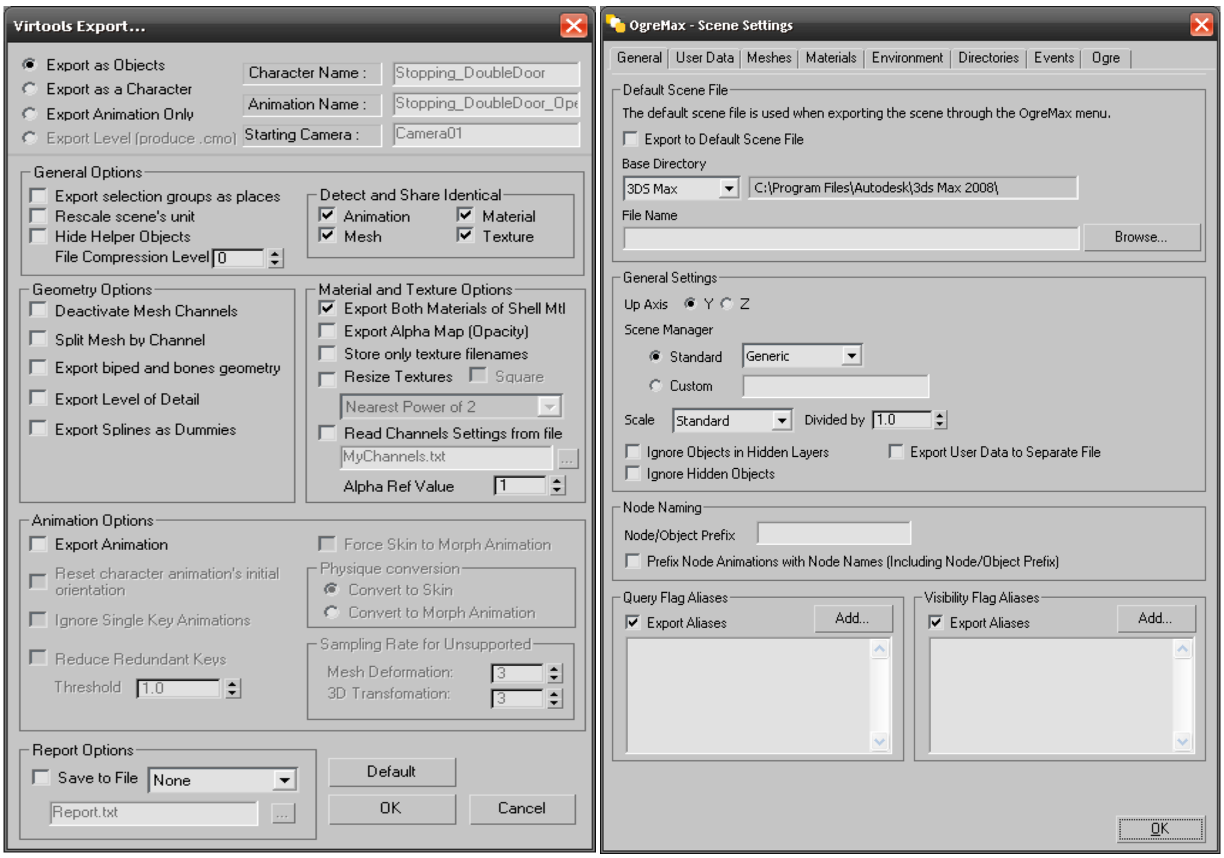

Figure 14a) Virtools exporter for 3D Studio Max, b) OGRE exporter for 3D Studio Max.

Smooth integration of 3D assets (Asset Pipeline)

The majority of 3D assets used in the simulation are created outside the game engine using specialised software packages like Autodesk 3D Studio Max and Maya before being brought into the game engine. This process of getting 3D content into the engine is extremely important and occurs repeatedly throughout the development stage. A loss of productivity can often be the result of deficiencies in this phase of the development process. An ideal game engine would allow the artists to seamlessly import the 3D assets into the engine without causing any major disruptions to the development team.

Most game engines have exporters that convert 3D data created in other software packages to a format that they can understand. Some engines are capable of reading in different modelling software formats natively, without the need for exporters. However, not all exporters support the same features. Therefore, it is necessary to test how well each game engine integrates 3D content created in other programs. An example export screen is shown in Figure 14

Virtools required an exporter to read 3D models from a 3D modelling program. The developers encountered some minor complications with importing certain animated assets into the virtual world for the Working at Heights Module. These were soon sorted out after consulting documentation and experimenting with the exporter's settings. Once these were sorted, there were no further problems with bringing assets into the virtual world and development continued smoothly.

The ideal exporter for a game engine would need to support the following technical features:

- 3D Studio Max, Maya or other popular 3D model file formats
- Multiple UV Channels per Mesh
- Vertex Colour support
- Multiple Materials per Mesh
- Material IDs
- Smoothing groups
- Skeletal animation
- Morph animation
- Animation blending
- Level of Detail support

Ability to customise graphics pipeline using shader languages (HLSL, GLSL, Cg, etc)

Rendering Engines render scenes via the traditional graphics pipeline. This consists of several stages where 3D models (constructed out of vertices) are transformed and then converted into pixels that are then presented to a display device.

Shaders are small programs that operate on vertices and pixels. They were introduced as a means to customise the different processing stages of the graphics rendering pipeline. Shaders have now become an essential component of any modern game engine, providing flexibility and features that cannot be matched by the traditional fixed function pipeline.

There are a number of popular shader programming languages that are in use and these languages are based on the two main graphics Application Programming Interfaces (API's): Direct3D and OpenGL. An ideal game engine would have support for at least one of these API's. This would allow shaders to be authored in HLSL (Microsoft's Direct3D High Level Shading Language), GLSL (OpenGL's Shading Language) or Cg, (nVidia's C for graphics) which can be used with either Direct3D or OpenGL.

The Working At Heights module made use of several custom shader programs to produce high fidelity and realistic graphics through the use of HLSL.

Support multi-user simulations

A multi-user simulation has many users who may be working co-operatively to complete some task, or be competing to finish a task in a minimum time frame. With the Working at Heights module, the final specification did not require multiple independent users. However, Virtools did have features which allowed for multiple users within the same virtual world. These features were not explored fully as they were not priority for the module. Multiple user support was made a requirement should the BHP-B ODX Project decide to incorporate that feature in future modules.

Users can interact within the same simulation through multiple input devices on one computer, or from separate computers networked to each other, running the simulation. Most of the game engines have some basic networking framework, allowing for simulations to be run across multiple computers. There are third party networking libraries that are available for use with the game engines that do not have native networking support. One such library is OpenTNL, Torque's Open Source Networking Library.

The ideal game engine would provide support for multiple-users in a simulation as part of its framework, allowing the developers to focus more on content instead of implementation details.

Support web deployment

The ideal game engine would allow for the project to be deployed via the Internet using a standard web browser. Many small game developers are attracted to the Internet as a deployment platform because publishing costs are lower (as there is no need for physical media) and it has the potential to reach a vast number of customers.

Many commercial game engines include support for web deployment, but the majority of AAA engines would not, as they are often singularly focused on delivering unmatched quality on a fixed set of standalone platforms (such as PCs and consoles). Open source engines usually do not support web deployment, but their open source philosophy means that the development of a custom web "plug-in" is possible.

Some game engines also have 'scalable' deployment capabilities, allowing for a program to be deployed as a web-based application, run on a desktop computer, or even on a video game console, without having to rewrite any of the code. This is a desired feature in a game engine; however this sort of scalability often comes at the cost of performance at either end of the hardware scale. Therefore the performance at both hardware platform extremes should also be taken into account when choosing a game engine.

Allows collaboration between developers

From working on the VR Mining simulations, there was some difficulty encountered for the programmers when working in collaboration on a particular simulation module. The version of Virtools that was used did not support collaborative development very well, which resulted in programmers being made solely responsible for individual scenarios to avoid conflict.

Rudimentary collaboration was possible, and took the form of programmers working on external subsets of a scenario that did not interfere with each other. These external modules were then merged into scenarios where they were needed. This was found to be error prone, as fine-tuning was often required to make sure that all changes were indeed mutually exclusive. The results that the programmers did not completely know how a module worked if they had not programmed it.

In the later stages of working with the VR Mining simulations, a version control system was put into effect. This was found to be highly beneficial to the development process, as files were kept organised, and changes made to each module were able to be documented and stored.

An ideal game engine should allow developers to work concurrently on a project. This can either be achieved through an inbuilt system allowing developers to work on different sections of a simulation, or by supporting integration with a version control system, such as Subversion.

Reasonable cost and licensing agreement

When considering a game engine, one of the most important factors to take into account is the cost (both monetary and time-based). This is a decision for the project manager to make, and relies on developers' input to make an informed decision.

Developers may have had experience using certain game engines and may recommend them based on how well the engine suits the specifications for the project. Learning time for a game engine must be taken into account if the developers have not used it before.

Open source game engines have the advantage of being ostensibly free, but depending on the licensing agreement, certain compromises may have to be made. These can range from limits in functionality, to restrictive distribution conditions. Open source game engines are often used in conjunction with other open source libraries, and these also come with the same caveats. Some open source engines offer an alternative license (at a cost) which removes these limitations.

Commercial game engines generally cost less than AAA game engines. However, some do require a one-off or annual licensing fee for development. Some commercial engines also require additional licenses to deploy or distribute the work. Virtools was one such game engine, with the licensing costs proving difficult to support by a small development team.

AAA game engines are the most expensive type of engine, and clients are often required to pay royalties on any sales that they make.

Ability to run across a cluster of computers and/or a non-standard display

Some VR systems involve the use of a cluster of computers, and non-standard displays, such as curved screens. Since games are traditionally run on single PCs or consoles, and output to standard monitors or televisions, game engines do not often have the ability to handle virtual reality systems.

Running a simulation on a cluster requires the computers involved to communicate the current state of the engine. This is done in a master/slave configuration with the master computer controlling input and distributing any changes to the slave computers.

Third party libraries exist that can implement clustering across multiple computers. These libraries can be used if the game engine does not natively support clustering. However, while open source engines would naturally be amenable to the inclusion of third party libraries, modifications made to commercial and AAA engines may involve more work, and require the usage of a different, or separate, licensing scheme.

Most VR systems use a non-standard type of display (such as a cylindrical or hemispherical screen). Outputting a correct image to screens of this type normally involves warping the original image, and blending between two or more images (if multiple projectors are used). Again, the engine will either have to support such set-ups, or accommodate the integration of a third party warping/blending solution.

The VR Mining simulations were implemented on the AVIE platform, which involved a cluster of 1 master and 6 slave computers to represent a fully immersive, 360 degree stereo environment. This was achieved using the clustering features provided by Virtools as well as a proprietary framework implemented by iCinema which performed screen warping and blending, and also provided additional clustering features.

Product support/Community

A good indication of the quality of a game engine is the size and activity of its community of users. A game engine may have good specifications, but may lack important documentation and have many unresolved problems or limitations.

Product support covers the following areas:

- Response times regarding bugs or queries
- Existence of a collective knowledge base
- Frequency of software updates
- Up to date exporters for 3D programs
- Evidence that the developers accept customer complaints/suggestions
- Examples or tutorials provided by the game engine developers.

The ideal game engine would allow developers to contact the game engine staff or developers should they have any problems or queries. It should also provide a Wiki, forum or mailing list for discussion and collaboration amongst other developers. There should also be ample documentation and tutorials to allow new developers to get up to speed quickly, and be able to understand and implement the more advanced features of the engine. The existence of a multilevel support structure such as this is a good indication that the game engine is popular and a quality product.

Some commercial engines provide this support or more for an additional, sometimes annual fee. Virtools had good product support, but the community support was disappointing, with infrequent activity and few truly helpful users.

Game Engines

Listed here are the game engines that were examined, along with a brief description of each.

Commercial Engines

Virtools - Comprehensive visual scripting language-based authoring package. UNSW development team has over 3 years experience using this package.

Quest 3D - Visual scripting language-based authoring package, with similar features to Virtools.

Unity - Inexpensive games engine with good 3D asset integration. Recently added Windows and iPhone support.

Torque - Ageing game engine with distributed networking capabilities.

C4 Engine - Inexpensive games engine with good licensing agreement. Supports COLLADA.

Virtual Battle Space - Military-based simulation engine currently used by the Australian Defence Force. Increasing in popularity amongst the serious games community.

AAA Engines

Unreal Engine 3 - Epic's major award winning game engine. Used both by Epic and a large number of third party developers.

CryENGINE 2 - 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.

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.

Results

The following game engines were tested thoroughly: OGRE, Virtools, Quest3D, Unity and Unreal Engine 3. Not all the game engines were tested due in part to time constraints or licensing issues.

Results for Specific Engines

The results of each of the tested engines will be examined in detail in this section.

OGRE 3D

Website: http://www.ogre3d.org/

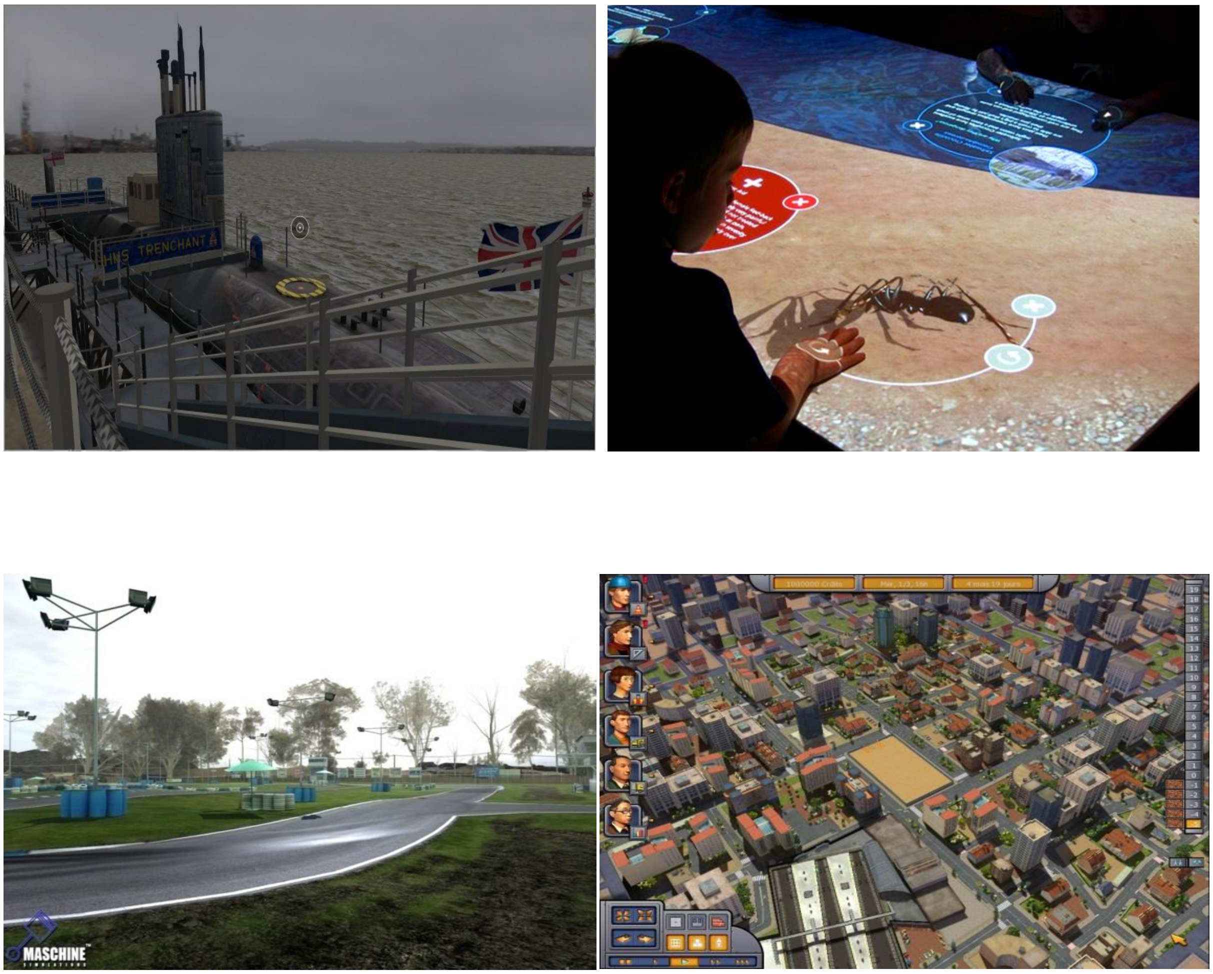

Figure 15 Some projects where OGRE has been used. **Top Left**: Sub Safe (Incredible Box), **Top Right**: Dangerous Australians (Lightwell), **Bottom Left**: Kart Sim (Maschine Simulations), **Bottom Right**: Building World (Creative Patterns).

The review is shown in Table 4.

Feature	Score
Development Time	6/10
3D Integration	8/10
Shader Support	8/10
Scripting	8/10
Product Support/Community	8/10
Networking	6/10
Cost/Licensing	10/10
Clustering	4/10
Web deployment	5/10

Table 4. Review of Game Engine Criteria - OGRE.

OGRE 3D is a popular open source rendering engine that has been in development since 2001. As it is solely a rendering engine, it does not classify as an all-in-one game development solution. However, it has been designed to integrate easily with external libraries. Developers can choose OGRE as the renderer for a game engine and leverage other free or commercial libraries for areas such as physics, audio and networking. This makes OGRE very flexible and customisable.

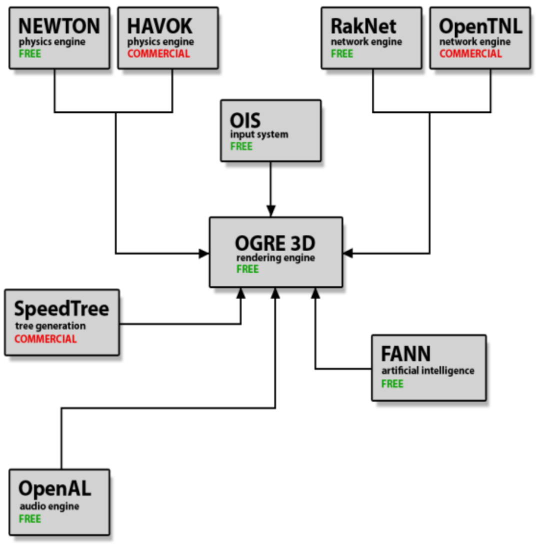

Figure 16 Example of integrating other libraries with OGRE

The OGRE rendering engine has additional well-maintained tools to assist in the development process. This includes 3D exporters to convert 3D models to an OGRE format. Using this tool, exporting the test models and importing it into a test scene are a straightforward process.

There are ample documentation online, active forums, and a well-maintained Wiki including several tutorials of varying scope and difficulty. The code required to load the model and walk around in it took about 10 minutes to locate, understand and reproduce. The example scene outline earlier was imported without any significant difficulty, and was rendered correctly at around 300 frames per second.

OGRE has bindings in a number of other languages as well. There are bindings to Python, Java and .Net, with the Python-OGRE project being the most notable, as it allows for rapid prototyping more so than the other compiled languages. The framerate of the same scene in Python-OGRE was half that of OGRE in C++, around 160fps at the same resolution.

Pros	**Cons**
Free under GNU Lesser Public License (LGPL) or GBP £899 for an alternative unrestricted license (OUL)	Not an "all-in-one" solution so it would take some time to set-up other components for the engine
Very customisable	No inbuilt clustering feature
No royalties or other fees	No inbuilt support for non-standard displays
Large community	Steep learning curve for non-programmers
Good 3D exporters available and tested	No inbuilt web deployment
Runs on Windows, MacOS and Linux	
Maintaining code and modules would be easier than visual scripting packages like Virtools and Quest3D	
Easier integration with existing source controls systems	

Table 5. Pro and Cons of OGRE.

OGRE would be an ideal engine to develop modules to run on a single computer. However, an additional third party library such as VRJuggler will be needed if clustering support is desired. This is not to be confused with multi-user capability, such as several users interacting within the same module from different computers. Similarly, if OGRE is chosen to develop modules for the AVIE/iDome, either an off the shelf commercial screen warping/blending package will have to be purchased, a suitable open source library located, or a custom solution will have to be developed, which would require a considerable amount of time and effort. Also, if web deployment is desired, a custom library will have to be developed.

Amongst the open source engines that we checked, OGRE had the biggest active community, supports more popular graphics technologies than other open source engines and has been used in a number of commercial games.

Virtools

Website: http://www.virtools.com/

Feature	**Score**
Development Time	9/10
3D Integration	7/10
Shader Support	8/10
Scripting	8/10
Product Support/Community	6/10
Networking	7/10
Cost/Licensing	6/10
Clustering	9/10
Web deployment	0/10

Table 6. Review of Game Engine Criteria - Virtools.

Virtools is the content authoring package that has been used by the development team for the past three and a half years to develop simulation modules. It was also used to develop the Working At Heights module. This game engine package includes physics, sound, networking and AI modules (some components need to be licensed separately to use). iCinema's AVIE and iDome systems have been developed specifically to work with Virtools.

Exporting from the 3D modelling program into Virtools has become trivial for the development team. The test scene was up and running in the Virtools environment in less than 10 minutes, with the ability to navigate around the scene. As the AVIE framework was developed in Virtools, the test scene was able to be run on the AVIE with some additional programming.

There is ample documentation for Virtools, with examples for each building block and several tutorials. Aside from a few translation errors and omissions (Virtools is produced by a French company) and a lack of help for certain 3D model exporters, the documentation provided was good.

Pros	**Cons**
3.5 years experience using program	Expensive licensing agreement
Existing infrastructure for AVIE/iDome integration	Undo function could be better
Clustering support	Fairly inactive community
Proto-typing/ Development is very quick	Some features cost extra
Existing pipeline/tools that we've developed	Visual scripts can be difficult to maintain
Good 3D exporters available and tested	
Fairly easy to learn for non-programmers	
Physics and AI packages	
Web deployment	

Table 7. Pros and Cons of Virtools.

Virtools has provided a forum for Virtools users to congregate, but developer activity is usually infrequent, and only a few other users are particularly helpful. Virtools also provides a one on one support program as part of its support agreement.

Virtools was used to develop the Working At Heights module as it was intended to work on the AVIE and/or iDome in the initial specification. Thanks to iCinema's framework, the Working At Heights module can be deployed on several non-standard simulation displays by just adjusting display, blending and warping parameters within the framework to match the screens to be used. Virtools also supports deployment to the web; however, custom Virtools libraries are not supported in the web player unless a considerable additional license fee is paid.

Creating content with Virtools is a quick process, as developers can drag-and-drop blocks of code rather than manually typing the algorithm implemented by the 'building blocks'.

Scripts written in Virtools' schematic programming language are not easily transferable to other game engine scripts. Functionality would have to be transferred block by block and changed based on the target scripting language, which would be quite time consuming. Generally, this is the case for other proprietary scripting languages too, should the need arise to port work from one engine to another.

Since the development team was experienced with using Virtools, the module was completed sooner than would have been the case if using another game engine.

Virtools would have been the ideal engine in every aspect, except that the cost and licensing agreement of it was quite expensive and more restrictive in comparison to other commercial game engines. Otherwise, it is a quality package that has proved very useful to the development team.

Quest 3D

Website: http://www.quest3d.com/

Feature	**Score**
Development Time	7/10
3D Integration	7/10
Shader Support	8/10
Scripting	7/10
Product Support/Community	8/10
Networking	7/10
Cost/Licensing	8/10
Clustering	8/10
Web deployment	8/10

Table 8. Review of Game Engine Criteria – Quest 3D.

Quest3D is a commercial game engine akin to Virtools. Like Virtools, it offers a visual programming environment in which developers can rapidly connect predefined behavioural blocks of code to develop complex systems. There is a fairly large and active community, and the demonstration projects available on their website show how capable the engine is. The biggest advantage of Quest 3D over Virtools is that their licensing agreement is transparent. Though per-seat licenses need to be purchased, there are no ensuing royalties or hidden fees.

Quest 3D has been used for simulations, architectural visualisations and games all around the world.

Although Quest 3D is a well supported and proven authoring package, its feature set offers no significant advantages over Virtools. Despite the fact that Quest3D uses a visual scripting system similar to that of Virtools, time and effort would still have to be spent in training and familiarisation. There isn't anything that Quest3D can do that Virtools cannot do. The lack of an undo feature will also hinder application development significantly and is a disappointing feature omission.

Pros	**Cons**
Transparent costs	No undo feature
License agreement is good (No royalties)	Visual scripts can be hard to maintain
Good 3D exporters available and tested	Learning curve
Networking/Clustering and web deployment support	No inbuilt support for non-standard displays
Fairly active community	
Impressive demos on website	

Table 9. Pros and Cons of Quest 3D.

The test scene was imported correctly and ran without any problems within the development software.

Unity

Website: http://unity3d.com/

Feature	**Score**
Development Time	7/10
3D Integration	9/10
Shader Support	8/10
Scripting	7/10
Product Support/Community	9/10
Networking	8/10
Cost/Licensing	9/10
Clustering	2/10
Web deployment	8/10

Table 10. Review of Game Engine Criteria – Unity.

Unity is another commercial game engine which is gaining popularity from developers around the world. The main advantage of Unity over the other engines is that it supports both Windows and Mac operating systems for development and deployment. It is the only commercial engine reviewed that can publish content directly to the Apple iPhone.

The integrated editor in Unity is reasonably simple, without much need for navigating through menus and interfaces. The Unity asset pipeline is one of the best that was reviewed. It supports several popular 3D file formats natively such as AutoDesk's .fbx format, allowing for smooth integration of 3D assets. However, unlike Virtools or Quest 3D it does not have a visual programming system which can inhibit rapid application development.

Unity supports the scripting languages Javascript, C# and a dialect of Python called Boo, allowing for increased expression in creating scripts for different purposes.

Since the .fbx format was natively supported by Unity, importing the test scene was extremely simple and was done with no trouble.

The Unity engine is well documented, shipping with sample scenes and many tutorials available on their website. There is also a rapidly growing support community, making the online forums and Wiki on the website particularly helpful.

Unity offers two development licensing options based upon the size of the development team: An Indie license ($199 USD) and a Pro License ($1499 USD) which is very cheap compared to the Virtools or Quest3D licenses. For iPhone and Wii publishing an additional license must be purchased.

There is no clustering support at all from the Unity engine, meaning further research and development will be required if modules made in Unity are to be deployed on the AVIE, iDome or other multiple screen system.

Pros	**Cons**
Support for many native and popular 3D file formats	No visual programming system
Supports both Windows and Mac development and deployment	No clustering
Support for the iPhone and Wii	
Relatively cheap licensing agreement	
Large community	

Table 11. Pros and Cons of Unity.

Unreal Engine 3

Website: http://www.unrealtechnology.com/

Feature	**Score**
Development Time	10/10
3D Integration	09/10
Shader Support	10/10
Scripting	09/10
Product Support/Community	09/10
Networking	09/10
Cost/Licensing	8/10
Clustering	04/10
Web deployment	2/10

Table 12. Review of Game Engine Criteria – Unreal Engine 3.

Unreal Engine 3 is an AAA game engine developed by Epic Games. It is a complete game development framework used by many leading game development companies around the world. Along with the other big budget games engines we investigated, its capabilities and feature set comfortably eclipse those of any of the commercial or open source engines currently available.

"Every aspect of the Unreal Engine has been designed with ease of content creation and programming in mind, with the goal of putting as much power as possible in the hands of artists and designers to develop assets in a visual environment with minimal programmer assistance; and to give programmers a highly modular, scalable and extensible framework for building, testing, and shipping games in a wide range of genres." - Unreal Engine website

Unreal Engine 3 includes a collection of powerful workflow tools. One of these, the Unreal Editor, allows artists to easily manage the 3D assets in the game engine itself, rather than using external programs. This gives them much greater control over the final result as well as allowing changes to be made more rapidly. It fills the void between the artists and the programmers.

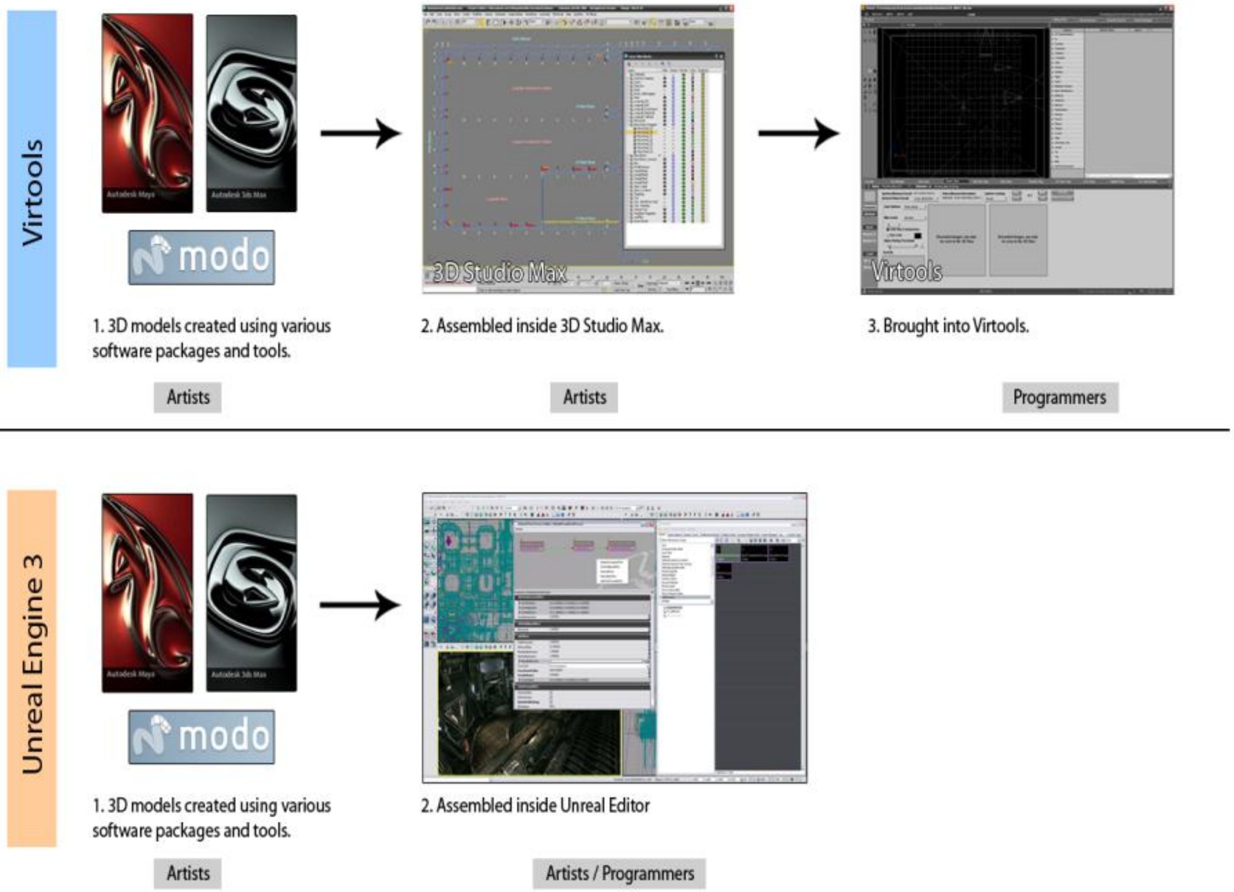

Figure 17. Top: Virtools content development pipeline, Bottom: Unreal Engine3 content development pipeline

Pros	**Cons**
Multi-award winning game engine	25% Royalties
Suite of tools to aid content development	No clustering support
Professional support agreement	No inbuilt support for non-standard displays
	No web deployment support

Table 13. Pros and Cons of Unreal Engine3

For non-game related work, the 10 developer license pack was quoted at $100,000 USD ($10,000 per seat). Considering that Quest3D VR Edition costs 9,999 EUR per seat, it is a very reasonable price. The only issue with the quote was that a 25% royalty fee was applicable to all project revenue. These prices are an initial quote and are likely to be negotiable.

There is no clustering support from the Unreal Engine, meaning extra work to deploy it on a multiple screen set-up like the AVIE. However, the engine supports extremely high resolution displays over multiple monitors, so a hardware workaround is possible to for modules made in the Unreal Engine to run on certain multiple screen yet single computer configurations.

Unreal Engine 3 is typical of an AAA game engine in that it is a highly tuned and specialised software package which allows developers to deliver gaming content for the most popular platforms (such as standalone PC executables and consoles). Unfortunately, this means that many features which may be found in commercial game engines (such as clustering, VR and web deployment) are not present in Unreal Engine 3, as these are rarely desired by the mainstream gaming public. Adding support for these features is possible (given the correct licensing agreement) but the proprietary, closed nature of the engine means that modification would be more difficult and time consuming than it would be with an open source alternative.

Game Engine Discussion

From the results, it was found that Virtools and Quest3D were well-rounded game engines well suited to the development team's needs. The major issues for Unity, Unreal and OGRE were the lack of clustering support and for Unreal and OGRE only, the lack of web deployment support.

The primary factors for choosing a game engine before the Working At Heights module commenced were rapid application development capability and overall cost. The specification of the first module also required that the modules run on the AVIE and iDome screens, and the specification was subject to frequent change, due to the research nature of the module. OGRE and Virtools and Quest were the two candidate game engines satisfying these criteria, but Virtools was the preferred engine, given the development teams' experience with it.

However, now all involved parties in the BHPB ODX Collaborative project have had experience in creating the Working At Heights module, future modules will have better idea of the required specifications and the project as a whole will progress more efficiently. Deployment through the web is an option under research and development, and Virtools, Quest and Unity support this platform natively. Unreal Engine will not support deployment on the web, as it is a high end engine with development centred on using a computer's full capability to run. OGRE may support web deployment if a suitable third party plugin can be found or even written.

To continue using the AVIE/iDome with iCinema's existing framework, Virtools is required. Thanks to the framework, all modules made with the framework are scalable from a single computer to the iDome to the AVIE screens. Currently there are no plans that we are aware of from iCinema to make a similar framework using any of the game engines reviewed in this report.

Quest 3D is similar to Virtools in capability and development speed, but cannot work on AVIE/iDome without significant research. The licensing agreement with Quest is somewhat cheaper than Virtools, but the costs outweigh the time required for the development team to familiarise themselves with the new development environment.

OGRE has good capabilities, and since it is open source, the price is definitely affordable. There are several open source and commercial third party programs/plugins for OGRE than can provide clustering support and eventually AVIE/iDome support, but these have yet to be tested thoroughly. Web support is also significantly lacking should development of future modules take that direction

Unreal Engine 3 is an ideal engine for a quality simulation that can be rapidly developed. Its feature set is unmatched by the open source/commercial alternatives, and it has a comprehensive support network. As mentioned earlier, support for high resolution output combined with hardware signal splitters allow for the Unreal Engine to run across multiple monitors, provided a hardware powerful enough to sustain decent framerates is used. Cryengine2 is also a good alternative, but as it was not able to be tested within this timeframe, it cannot be compared properly to Unreal Engine 3.

Unity recently announced support for Windows and the iPhone platform. With its low cost, good file format support and multiple deployment platforms across single computers/processors it is well suited to the casual games community. However, there is no clustering support provided with Unity.

Game Engine Conclusion and Recommendations

This section has evaluated several game engines to use as the development platform for the BHP-B ODX Collaborative Project. Based on the results, this report recommends using Unreal Engine 3, Virtools or OGRE as the development platform.

Virtools is a good platform choice as development times are fast, the programmers have experience using it and the simulations produced are of good quality. It is suited for a multiple computer/screen set-up, due to its clustering features, with the support of iCinema's VR screen framework. The licensing costs are the main letdown for Virtools, as it has become quite expensive to maintain.

Development for the AVIE/iDome, or any general clustering/non-standard display solution, is possible with Unreal Engine, OGRE and Unity, but as mentioned earlier, it will require either the integration of existing off-the-shelf/open source clustering and screen warping/blending packages, or the development of a custom library, which will impact total development time. Between these engines, OGRE is the most recommended, as it has been designed to accommodate third party libraries.

The Unreal Engine was found to be too costly for the small development team. This was a significant disadvantage for an otherwise excellent game engine.

OGRE is the most suitable game engine for developing future modules as it is the cheapest to maintain and has a good set of features relevant to the development team's requirements. OGRE lacked support for the AVIE/iDome screens and will require significant development to implement this feature.

Unity was a good game engine alternative should future modules not require AVIE support. It will take considerable time to develop support for the AVIE.

Overall, taking into consideration the price, quality, development time and flexibility of the game engines reviewed, OGRE is the best choice of game engine to use for developing simulations across different platforms. Virtools is a close second, only due to the licensing costs required by the software.

6. Module Development

The development of the Working at Heights Module is the core component of the project and the aim was to provide a working prototype system suitable for the South Australian mining industry. The module was also developed in such a manner that it would have relevance to other industries in South Australia and elsewhere such that is could be used as a demonstration and as a pre-cursor to other module development.

The development of the module was based on a collaborative model with six main contributors.

- UNSW, School of Mining Engineering.
- University of Adelaide, ACVT,
- BHP Billiton ODX Project.
- RESA.
- TAFESA.
- SkillsDMC.

UNSW and Adelaide were the Chief Investigators and Project Directors and worked with the collaborators to develop the module.

The collaborators provided cash and in-kind funds to allow the project to function and BHPB were the main input of information towards the operational side of module development. External training provider SRTA also engaged in providing material and facilities to test the module.

TafeSA, RESA and SkillsDMC provided extremely valuable steering committee members and also invaluable input into the project direction – their experience in training and education was invaluable. The structure required to bring the module to completion is shown in Figure 18.

Managing the different interest and agendas of the people and organisations involved the project was a challenge –especially due to retrenchments within BHPB during the project, but overall the module progressed well and was kept within the bounds of what is achievable in such a small project with so many partners over such a short time frame. The collaborative experience was excellent and added great value to the project.

The scope of the model and module development is shown in Table 14.

Working at heights scenario: 3D Asset generation	
Sub Module 1.0 - Portable Ladders Scenario Meshes	
	3D Meshes
	Environment Meshes
	Ladder Meshes
	Human Meshes
Sub Module 2.0 - Scaffolding Scenario Meshes	
	3D Meshes
	Basic scaffold mesh
	Mobile scaffold mesh
	Scaffold hazards
Sub Module 3.0 - Elevated Work Platform Scenario Meshes	
	3D Meshes
	Elevated work platform mesh
	Electrical distribution wires on poles
	Electrical distribution wires on towers
	Safe work load of basket
	Fibreglass 200kg
	Steel 250kg
	Show position adjacent to excavations
Sub Module 4.0 - Forklift Cage Scenario Meshes	
	Forklift cage
	Correct location and positioning
	Locked into position
	Bad example pallet mesh work platform
Sub Module 5.0 - Safety Harness Scenario Meshes	
	Safety Harness Mesh
Sub Module 1.0 - Portable Ladders Scenario Interaction Programming	
	Plan out the storyline and outcome for interaction with the ladder sub module
	Identify correct and incorrect methods of using a ladder
	Face towards ladder while climbing up and down
	Move up or down one rung at a time
	Three point of contact
	Body centred and within stiles
	Climb down ladder to reposition it
Sub Module 2.0 - Scaffold Scenario Interaction Programming	
	Plan out the storyline and outcomes for interaction with the scaffold sub module
	Identify correct and incorrect methods of using a scaffold
	Scaffold construction (2m or more)
Sub Module 3.0 - Elevate Work Platform Scenario Interaction Programming	
	Plan out the storyline and outcomes for interaction with the elevated work platform sub module
Sub Module 4.0 - Forklift Cage Scenario Interaction Programming	
	Plan out the storyline and outcomes for interaction with the forklift sub module

Table 14. The original 'scope' of the project (Superseded through discussion).

The aim was to focus on high risk areas of the site. The development of the pilot module was as 'proof of concept' and generated over the majority of the project timeframe.

It should be noted that the model developed considerably when compare to this list of objects as a result of discussion and compromise with the various teams. The 3D model and interaction were developed as part of an ongoing process of improvement as occurs in any research and development process.

The Mining VR team from UNSW and Uni' of Adelaide met on a regular basis with the industry experts and collaborators. The process of model and module development is common in prototype development and is shown in Figure 19. The cycle shown in Figure 19 is essential and allows the development of the module to become a process of evolution which is important in the research and development stage, however, much tighter control over the number of cycles and scope of the process must be determined in a production environment.

An area relating to the planned BHPB ODX site was chosen to be modelled and this is represented in Figure 20. The infrastructure within the model was built using traditional modelling methods and CAD drawings. A screen shot of the module model is shown in Figure 21.

The module user interaction was design through discussion with the learning and teaching personnel at BHPB ODX and consultation with industry trainers. A formal instructional design was also developed at UNSW for experimentation.

The process of 3D model generation was performed at UNSW and the site model and infrastructure were developed in 3D Studio Max and MAYA and subsequently exported to Virtools as the interactive engine.

The module development process requires considerable communication for the module to be developed effectively. However, in an early stage pilot project it is difficult to quantify the exact specifications and direction of the module. The concept of simulation is new to the mining industry; however, the produced model was of very high quality. Module descriptions are located in the Appendix. The key sub modules developed were,

- Correctly Erected Scaffolding,
- Incorrectly Erected Scaffolding,
- Open Trench,
- Ladders: Change Light Globe,
- Elevated work platform.

The interaction with these modules is based on Working at Heights documentation from BHPB OD site and was developed in consultation with BHPB staff. Some of these staff subsequently became contractors following the suspension of ODX operations in early 2009.

Figures 18 and 19 show the complexity of the project and its communications.

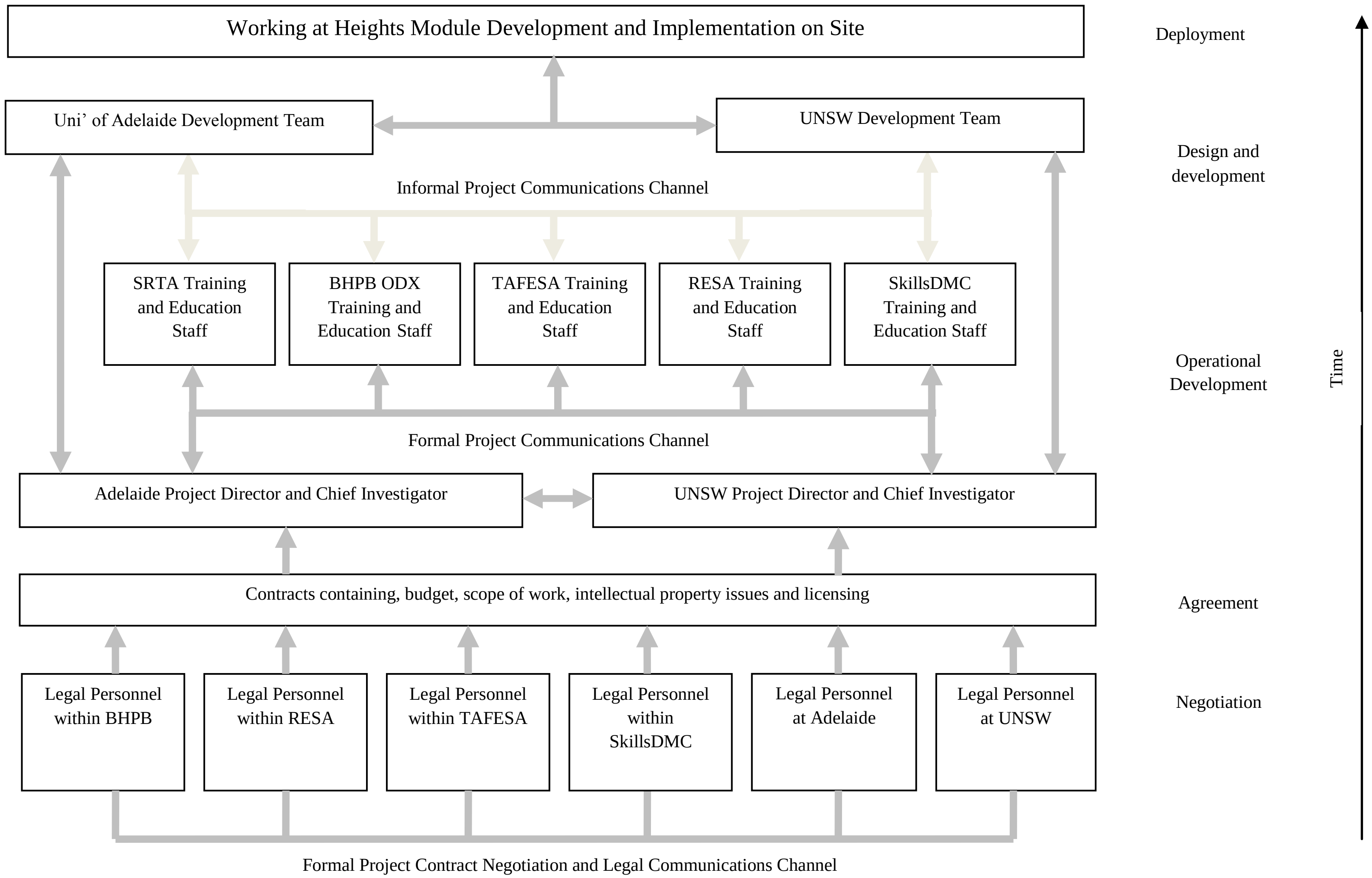

Figure 18. Foundations to collaborative module development.

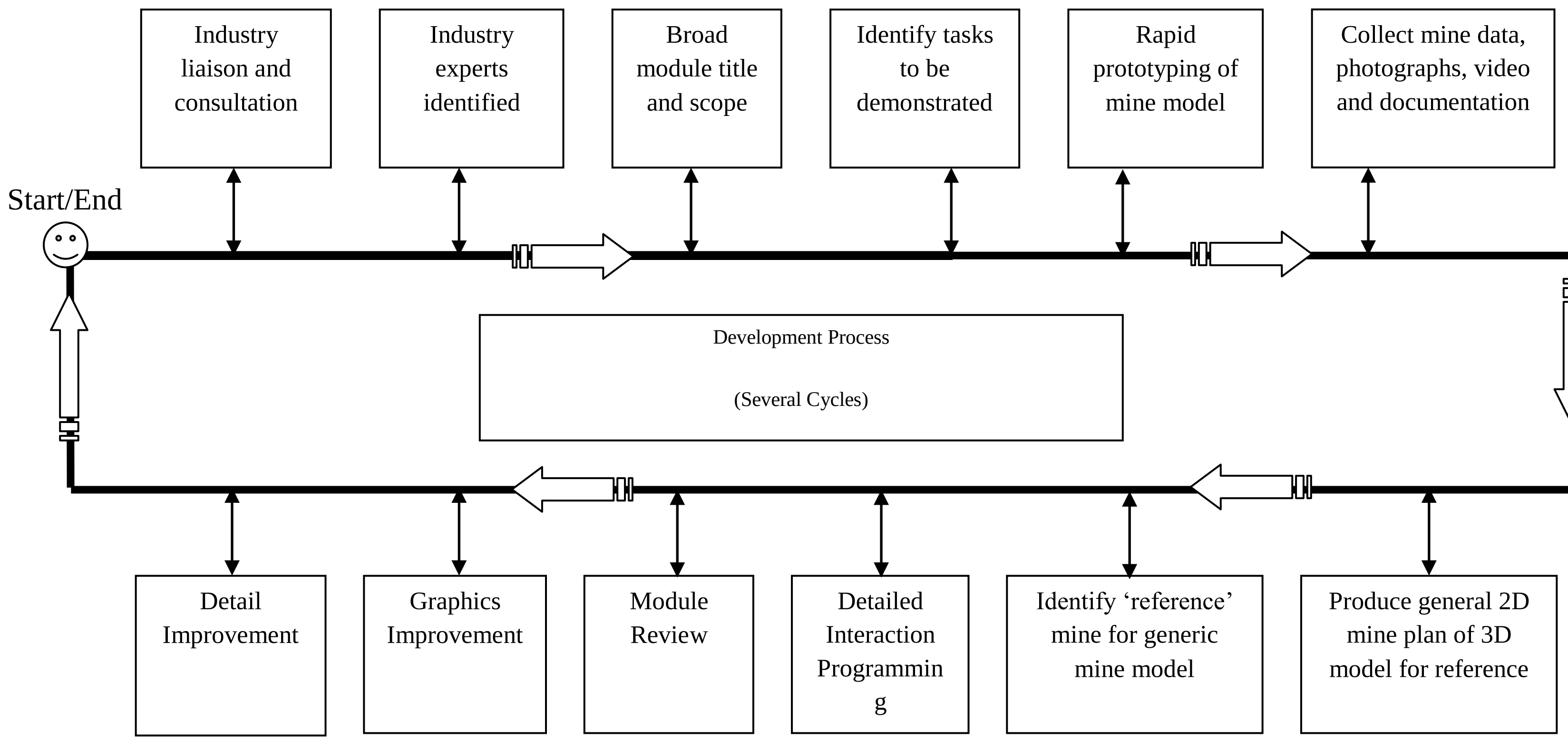

Figure 19 Module development cycle – several iterations are required.

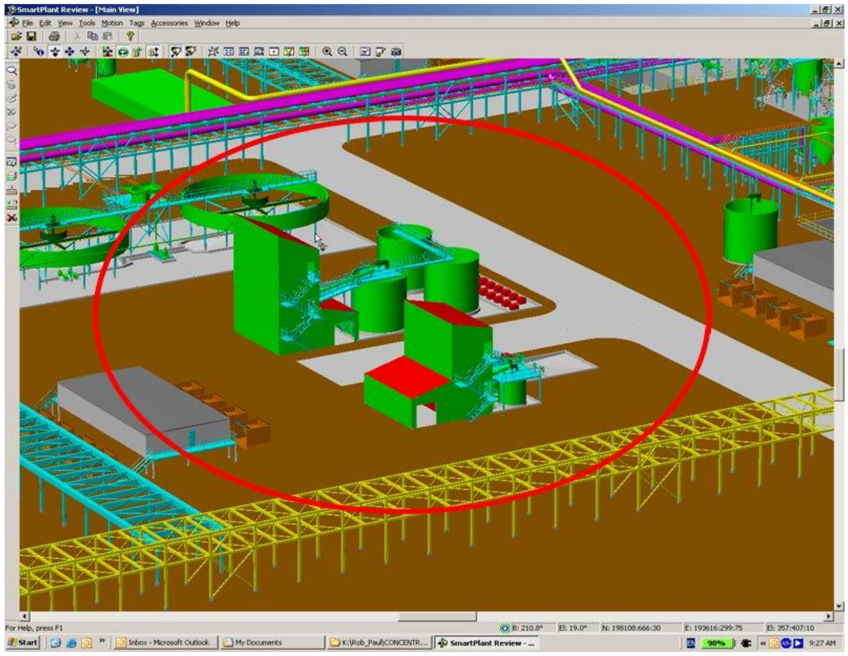

Figure 19. Area of the planned BHPB ODX selected for modelling.

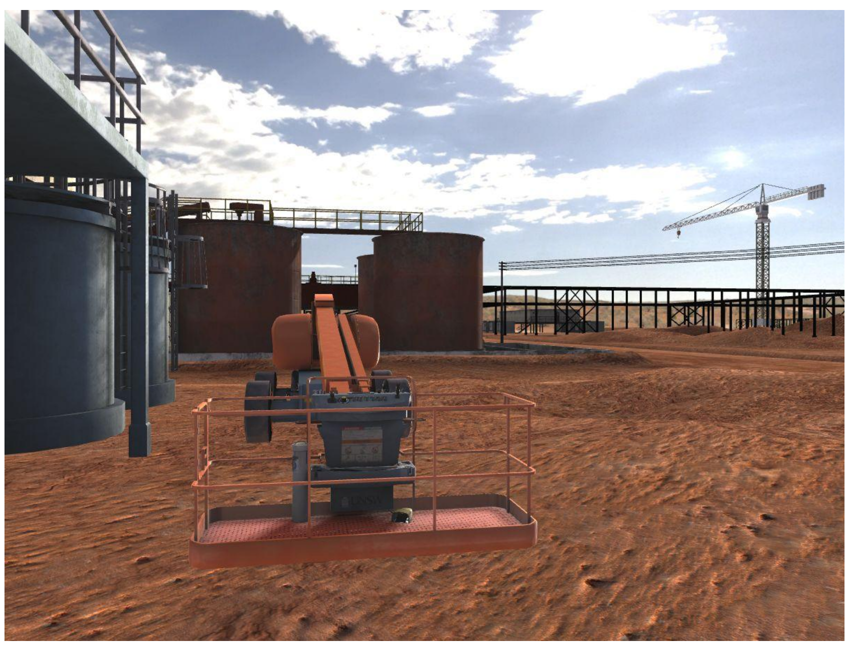

Figure 20. Screen shot of the built model.

7. VideoTrace

The aim of this section is to review the use of VideoTrace as a tool for model generation. The review is approached from both a developer perspective and a user perspective. The results show that VideoTrace software has application in the generation of 3D content. The software currently has limitations identified by the review but these issues are potential improvements to the software's usability.

Developer Perspective: Using VideoTrace to Model Geometry for Virtual Reality Simulations

Building 3D computer models has previously been a time-consuming task that requires a skilled operator many hours to complete. Models are traditionally built in a 3D modelling program, such as 3DS MAX, by employing a set of operations in a completely synthetic co-ordinate system, i.e. in a space that has no relationship with any image of a real-world object. In general, a model is built by 'outwards' by iteratively modifying a primitive until a desired shape is created. This is a time-consuming process–even for a skilled modeller – and the accuracy of the computer model with respect to a real world model is completely dependent on the modeller's skills.

In contrast to the completely manual process of 3D modelling, an active area of research in the field of computer vision is that of automatically estimating 3D models from a set of real-world reference images. This problem is under-constrained; there are provably an infinite number of 3D models that can generate a finite set of images. VideoTrace is a research tool developed at the University of Adelaide which is able to reconstruct videos by relying on user input to resolve the problem of inherent ambiguity. VideoTrace bridges the gap between 3D modelling in a completely synthetic co-ordinate frame and reconstruction techniques that automatically builds models from a video of the real-world. The result is a 3D model that is built simply and intuitively from the input images as reference, and more importantly is able to generate a 3D model to match the geometry that is captured in the video.

As a research tool, VideoTrace has proven successful in reconstructing a number of 'toy' sequences which are used to test the reconstruction algorithms. As a production tool, however, testing VideoTrace as part of a 'real-world' production would allow us to better identify end-user requirements and, in turn, adapt VideoTrace to better automate a larger part of the reconstruction pipe-line. The mining simulation project with the University of NSW provided an excellent opportunity to test VideoTrace as proof-of-concept as a production-quality tool. Working with the development team at UNSW allowed us to identify some areas of further work for the development of VideoTrace.

VideoTrace: Overview

VideoTrace is a technology for building 3D models of a scene captured by a moving video camera. The process involves filming an object of interest, such as a building or a car, and allowing the user to interactively trace out regions of interest on the video frames. The 3D position of each user operation is automatically computed by VideoTrace, allowing the user to build a three-dimensional model from a set of two-dimensional user-operations. The user must first film the object of interest using a standard, ‘off-shelf,’ video camera. The goal is to capture the appearance of the object from a sufficient number of views such that all surfaces are visible.

The video is then pre-processed into a ‘traceable’ form by estimating the real-world camera’s position relative to the object for every frame of the video. This Structure from Motion process is automatically performed by VideoTrace only once per video. The result is a set of cameras and associated video frames in a three-dimensional co-ordinate frame.

A by-product of the structure from motion process is a set of 3D features that corresponds to dominant features in the images. The reconstructed features form a ‘point cloud’ which represents a partial 3D representation of the object depicted in the video. The point-cloud is turned into a solid, polygonal model by an interactive, user-driven process.

VideoTrace requires the user to sketch out facets of the model in 2D as they appear in the video. Using the estimated camera positions and 3D point cloud from the previous stage, VideoTrace automatically computes the most likely 3D position of the user’s 2D sketch. If a 3D position cannot be determined, or if the reconstruction needs to be improved, the user is able to drag the sketch into position in a second view again, using only 2D operations that enables VideoTrace to triangulate the sketch in 3D.

By defining a series of polygonal facets that are welded together, the user is able to build a ‘water-tight’ polygonal model of the scene depicted in the reference video. The advantage of VideoTrace over 3D modelling programs is a significantly simplified work-flow. Rather than building a 3D model in a traditional 3D modelling program by modifying primitives until a desired result is obtained, VideoTrace requires only that the user trace over an image of the real object. VideoTrace automatically solves the 3D problem a task which is difficult for a human while relying on a human's natural ability for identifying planar regions. The process is able to generate models with as much detail as required by the user.

Modelling real-world geometry with VideoTrace

Modelling real-world objects with VideoTrace is a three stage process, with each stage being dependent on successfully completing the previous stage. The work-flow, illustrated in Figure 21 requires,

- Filming—a 'reference' video sequence of the real-world object is captured by a conventional video camera;
- camera estimation–the video camera's motion and partial reconstruction in the form of a 3D point cloud is automatically estimated; and
- Modelling and texturing–a 3D model is built by sketching planar regions in the reference video.

Filming

The filming stage involves capturing the appearance of the object with a conventional video camera. This involves positioning the object for filming; adjusting the camera for acceptable exposure; and filming the object in a single, smooth motion. Filming a sequence requires only a few minutes to capture the footage. This is chiefly a limitation of the camera tracker, whose reliability degrades as the number of frames increases due to camera drift. Although only one sequence can be used, multiple sequences may be required to ensure at least one is suitable. This is particularly relevant in cases where travelling to remote sites for re-shooting is not feasible.

There are a number of practical considerations that affect the suitability of the video sequence for subsequent stages. The video sequence must be suitable for the camera estimation process. As this process involves matching small windows between subsequent frames, this process is more reliable if the camera moves slowly and smoothly. Furthermore, it is advantageous if the sequence contains a mixture of foreground and background elements i.e., structure at varying depths to facilitate a reliable reconstruction in the second stage.

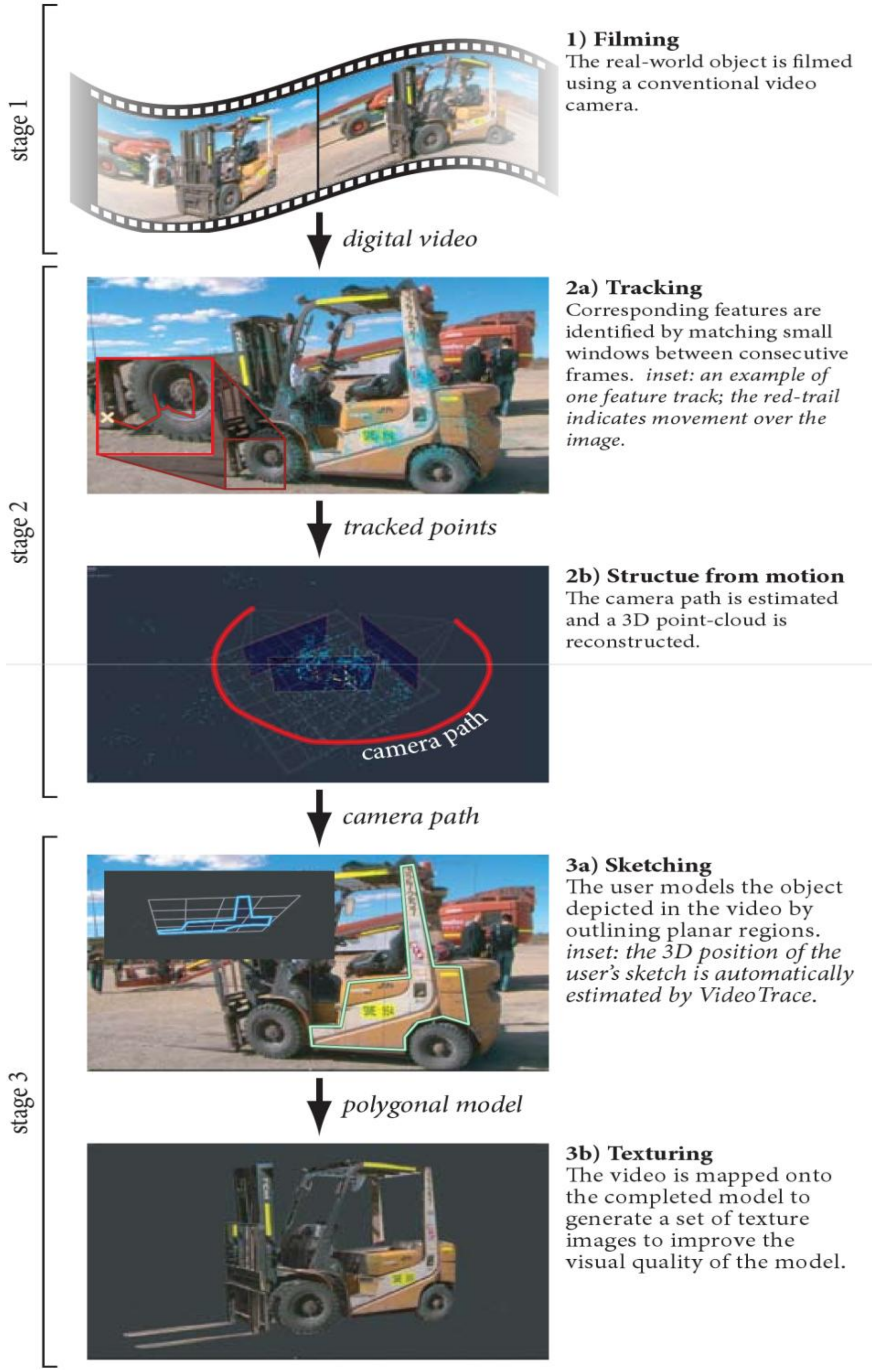

Figure 21: The VideoTrace work-flow is described by three principle stages, from filming the object to texturing the completed mesh.

Although a wide variety of scenes contain a sufficient distribution of features, synthetic features (‘fiducial markers’) may need to be added to the real-world object to ensure a reliable track. As the user is required to trace the outline of the surface in the video, the camera operator must ensure that all salient surfaces of the object are visible in one sequence. Meeting this requirement may involve preparing the object for filming. A vehicle, for example, may need to be parked in an open area and configured in a pose suitable for tracing, such as elevating the work platform to a particular position.

Finally, the sequence must be correctly exposed. All CCD/CMOS imaging sensors have a finite capacity for registering light. Admitting too much light will saturate the sensor and clip the signal; similarly, under-exposing the image will not admit sufficient light to disambiguate small image windows. Clipped highlights and under-exposure will invariably lose image detail, which affects the number of features that can be recovered, and consequently can have adverse repercussions on the quality of the camera estimation process in the second stage. Care must be taken to ensure the scene is correctly exposed; but compounding this problem is the requirement that the exposure remains fixed throughout the video sequence. In some cases, the scene’s reflectance can be significantly different over varying viewing directions, which can make challenging the problem of finding a single exposure that is suitable throughout the sequence.

Camera estimation

The second stage estimates the position of the camera relative to the first frame for each frame in the sequence, known as the Structure from Motion problem. This process involves identifying the projection of a 3D point in a number of frames; the camera motion can then be estimated by finding a camera path that is consistent with these projections. In general, this process is entirely automatic, but in some instances may require manual correspondences before the camera path can be estimated. Key to camera estimation is the problem of identifying the projection of a scene-point in more than one image. This problem is typically solved by finding an ‘interesting’ region in one image, and locating the most similar region in the next. The goal is to identify regions in consecutive frames that correspond to the projection of the same 3D point. Most approaches make assumptions about the camera movement in order to make this problem tractable, typically by assuming that the camera moves slowly to minimise the distance between the projection of a point in one image and its projection in the next. Feature tracking in general produces acceptable results automatically, but can require human intervention in difficult sequences where features cannot be reliably tracked, or not tracked at all. In these cases, a user is required to manually identify a corresponding point in a large number (if not all) of the frames in the sequence. It is often only necessary to provide a sufficient number of points at varying depths across the image to guide the automated process in finding further features. In severe cases, however, the user may be required to manually track a large number of features in every frame.

This process, unfortunately, is significantly time-intensive. Even if the automatic process was successful, it is often useful for a user to mark correspondences between the first and last frame to minimise camera drift (and, consequently, improve model accuracy) by 'closing the loop.' The camera motion consistent with the set of projections can be estimated from the set of potentially corresponding features. This, too, is an automated process which is often very reliable; but the calibration can be improved by manually marking sets of planar features. A by-product of camera calibration is the reconstruction of the 2D tracked features into a set of 3D points in world-space. As these points are fundamental to the modelling stage, care must be taken to ensure a sufficient number of points were reconstructed on the object that the user wishes to model. Once the 3D structure has been estimated, the sequence is exported to VideoTrace in the form of camera model parameters, the 3D point cloud, and radially undistorted reference video.

Undistorting the sequence involves warping the reference video in such a way that straight lines in the world appear straight in the image. This process corrects non-rectilinear distortion induced by lenses, bringing the image into a form that can be represented by VideoTrace's camera model. The time taken in the second stage depends on the video resolution and number of frames in the sequence. A sequence of approximately 600 frames with 1920_1080 pixels (typical of the sequences used to capture the vehicles used in the project) took approximately 10 minutes to estimate correspondences. If manual tracking is required, however, it might take a skilled operator up to an hour to track a number of points sufficient for calibration and modelling in the next stage. Estimating the camera motion depends on the number of frames in the sequence and the number of tracked feature points. A sequence of 600 frames with approximately 600,000 feature observations corresponding to 3,600 features took approximately 7 minutes to calibrate. In some cases, additional constraints were manually provided by marking sets of planar points, but this took only 3 additional minutes. Undistorting the reference was the most time-intensive process; the 600 frame sequence with 1920_1080 pixels took approximately 20 minutes to undistort. Including the time taken to decompose the video into a set of image frames, the entire camera calibration process typically took approximately 40 minutes.

Modelling

3D modelling is the process of constructing a polygonal 3D mesh to represent some desired shape. VideoTrace allows the user to model the object depicted in the video sequence via an iterative process of sketching planar facets over the object's projection in the video. The sketch is positioned in 3D on the basis of the cameras and point clouds that were estimated in the previous stage. Each planar region can be connected to new sketches, and in this manner a user is free to model as much detail in the video as required, from coarse, low-polygon approximations, to detailed, high-polygonal models.

Key to VideoTrace's interface is a series of 2D user-interactions made directly over the reference video. Each sketched region is assumed to enclose a planar facet in world-space; a region might enclose the side of a forklift, for example, but not include the sides of the roof-strut. A single 2D polygon does not contain sufficient 3D information. Although it should be noted that 3D models are not typically built in this fashion in 3D CAD software, 3DS Max would, in this case, define a 3D position by assuming the polygon is co-planar with a world plane, such as the X/Z plane. The user would then manually adjust the vertices using world-space transformations on the vertices, edges and faces.

The process of manually positioning geometry in this manner is very time-intensive, particularly if the goal is to align the geometry such that its projection is coincident simultaneously in all frames of the reference video. Although an infinite number of planes project to a 2D region, VideoTrace uses the 3D point cloud from the previous stage to infer the 3D position of the planar sketch. The features tracked in the previous stage define a sparse set of visible point samples with corresponding 3D structure. The user's sketch implies a selection of these points. The points that fall within the boundary of the sketch are used to fit a 3D plane by finding a plane that best approximates the points implicitly selected by the user. The automatically inferred 3D plane and the user's 2D sketch defines a unique planar facet correctly positioned in world-space. VideoTrace clearly relies on tracked features to infer 3D structure.

The camera tracker in stage 2, however, may be unable to identify a sufficient number of feature points on all surfaces that the user wishes to model. In this case, the user's sketch cannot be correctly positioned automatically by VideoTrace. The user is therefore required to provide additional constraints by marking the sketch's position in a second, widely separated view of the object. This process 'anchors' the sketch in two views of the object, allowing VideoTrace to triangulate the points along the sketch to infer its 3D position.

A 3D model can be built in VideoTrace solely on the basis of user-guided sketches. Sketched planar facets can be used by VideoTrace to better estimate the 3D position of connected facets by using the 3D information of coincident edges. In this manner the user can iteratively build a complete model through piece-wise sketches.

A number of additional tools within VideoTrace can save duplicating effort for structured objects by extending the idea of planar sketches to 3D operations on those sketches while still using the 2D sketching interface. The two key tools that extend VideoTrace's sketching functionality are the mirror and extrude tools. Both tools duplicate an existing set of sketches and allow the user to reposition the copy elsewhere in the image. The copied geometry is then connected to the original by adding new polygons between corresponding edges.

The two tools differ only in the orientation of the duplicated geometry: whereas the extrude tool translates the geometry to a new position, the mirror tool first reflects the geometry about the translation axis. Mirroring and extrusion are extremely useful for a large number of man-made objects, which tend to be high degree of symmetry. The advantage of the extrusion and mirroring tools is that it significantly saves modelling effort. Not only does it save the user from sketching the duplicate face, but it automatically fills in the connecting sides. These properties are particularly useful in cases where only one side is visible and the user must guide VideoTrace to make inference about occluded geometry.

While modelling in VideoTrace is partially automated, but it is also an art that depends on the presence of features tracked in the previous stage. Both attributes have an affect on the amount of time taken by a skilled operator to generate a suitable 3D model. Although VideoTrace relies on features, a typical camera track usually has a sufficient number of 3D points to quickly and automatically bootstrap an initial, coarse model. With sufficient points, the modelling a crude, low-polygon model of the fork-lift may take approximately 10 or so minutes. In cases where an insufficient number of features were tracked in the previous step, the user is required to anchor sketches in two or more images. This requirement significantly slows the time taken to model a scene. From the crude polygonal model, a user is able to refine the geometry to any desired level of detail. Accordingly, the time taken to build 3D models depends on the level of detail required. The models generated for the Mining VR simulation in Section 3, for example, took approximately one hour each to model.

Using VideoTrace on the mining VR project

Due to the time required to model 3D geometry, VideoTrace is ideally suited to rapidly generate models of vehicles for inclusion in the mining simulation developed by UNSW. A number of video sequences were captured from BHPB's Olympic Dam Mine. These sequences were principally of car-sized vehicles–such as a scissor and fork-lifts–but also included a larger elevated work platform and the facades of some key structures at Olympic Dam.

The sequences which were the most promising and useful for the mining project were modelled with VideoTrace, and the resulting polygonal meshes were sent to the developers at UNSW. A number of utility vehicles were successfully modelled with VideoTrace, including a forklift, an elevated work platform, a scissor lift and a boom lift. The sequences were more complicated than the commercial vehicle test sequenced used for the development of VideoTrace, for two reasons:

- The vehicles were characterised by fine 'wire structure' such as handrails, wire-guards and pipes; and
- In the case of the elevated work platform, the entire object was not visible in a single frame.

These properties demonstrated VideoTrace's ability to adapt to these unseen test-cases, but also inspired new tools to facilitate the modelling process. The 'wire structure' of the vehicles caused problems for the feature tracker, which, in turn, meant the automatic 3D modelling aspect of VideoTrace could not be used. The feature tracker is an automatic and integral part of the pre-processing stage, and it relies on identifying the corresponding location of an image window through the video sequence. The feature tracker relies on the window image being stable so that it can automatically match the window in subsequent frames.

The problem with thin pipes, however, is that as the pipe is visible in only a small subset of the window, the window's appearance is unstable. Consequently, the feature tracker is unable to identify features on either the pipe or any part of the scene in the window. As VideoTrace relies on features for its plane fitting algorithms, it is unable to automatically compute the 3D position of the user's sketch over the pipes.

VideoTrace allows the user to identify manual correspondences, however, which allows the user to specify the position of the pipes in 3D without the need for automatically tracked features. While this approach worked, it is a time-consuming because the core functionality that enables VideoTrace to simplify the modelling work-flow is not used. The problem of modelling hand-rails inspired a new tool for extending geometry in cases where feature points could not be identified.

A new ability to define snapping planes in 3D was added, so the user can define a plane in 3D on the basis of existing points, but allow the user to extend this plane into feature-less regions. The user must first select a solid, coplanar region of the image to define a 3D plane using the plane fitting algorithms that are used for modelling. The 3D position of a user's sketch of the hand-rails can then be estimated on the basis of this 3D snapping plane; the 3D position is defined by mapping the 2D sketch onto the snapping plane. Consequently, the user does not need to manually triangulate every vertex of the handrails, significantly speeding up the modelling process even in areas where no 3D points were automatically detected.

Despite the challenges presented by the sequences, VideoTrace was successfully used to model a number of vehicles for the Mining project. The existing functionality was able to model difficult parts of the scene, and our experience with the modelling process for this project inspired a new tool that was developed to rapidly model a number of additional sequences. The resulting meshes were sent to UNSW for inclusion in the mining simulation.

Future work on VideoTrace

Our experience with the mining project identified a number of avenues for future development with VideoTrace. The collaborative project identified two main areas for future work: firstly, a process of facilitating texture editing by giving the user the ability to control texture unfolding; and secondly by including the ability to register multiple video sequences.

Texturing is the process of mapping the reference video onto the polygonal mesh. This process greatly improves the visual quality of the model without requiring additional geometry. Textures are created by copying fragments of the reference video onto a texture image which is 'draped' onto the completed model. As this process is automatic, VideoTrace's texture mapping is an un-ordered assignment between video frames and texture images. Although the fact that the process is unordered does not have an adverse affect on the quality of the model, the ad hoc texture arrangement made it difficult for the developers at UNSW to modify the textures. Modifying the textures is important for 'cleaning' the images and removing shadows. To facilitate modifying the textures in software outside VideoTrace, some methods for improving the ordering process were investigated. An initial algorithm that unfolded the model in such a way to maximise contiguity was implemented. While the algorithm partially addressed the problem, we discovered that a user-guided process was still required. A process that allows a user to unfold the model is an avenue for further work.

The capability to model from multiple video sequences or still images would be particularly useful addition to VideoTrace. VideoTrace is currently only to able track an object filmed by a single camera over a relatively short sequence. Furthermore, the camera must move smoothly and over a sufficiently wide distance so that the camera positions can be estimated.

Unfortunately, part of the difficulty in filming sequences at Olympic Dam was that a number of restricted areas meant that some objects could not be filmed with sufficient coverage and base-line for modelling VideoTrace. Being able to register multiple video sequences and wide base-line images within VideoTrace is an area for future work that would dramatically increase the scope for modelling large structures such as buildings.

Modeller Perspective: Comparison of VideoTrace to traditional modelling techniques

The aim of this section is to review the VideoTrace software and its suitability for the production of models intended for use in an interactive 3D Working at Heights simulation. VideoTrace is a 3D modelling system that allows the user to rapidly model 3D objects using a captured video of the scene. In order to compare VideoTrace to the traditional modelling process for the production of both high-resolution primary models and low to medium resolution secondary models, several standard pieces of work site equipment were chosen, and the models were then constructed in VideoTrace and Autodesk Maya (an industry standard 3D modelling and animation package). The workflow involved in producing a 3D model using VideoTrace is outlined in detail, and compared to the traditional 3D modelling process. Finally, we outlined the benefits and drawbacks of the VideoTrace method and identified areas in which it could be improved.

Introduction

Normally, the production of a 3D model for inclusion in an interactive 3D application requires the use of a 3D modelling package such as 3D Studio Max, and an artist with the appropriate skills. This naturally proves to be a substantial barrier of entry for those who wish to construct their own models, but have no training or experience with these packages. Models are built with the aid of a set of artificial "reference frames", which do not map to any real-world positions, and are usually constructed with the aid of references such as photos, videos, blueprints and CAD drawings, which are often arranged in a random fashion. These references are then used by the artist (with a certain degree of interpretation) to construct a polygonal wireframe representation, or "mesh", of the object. The mesh is then prepared for texturing, which allows for 2D images to be correctly mapped onto the surface, and then the textures are created manually by the artist. All of these steps require a certain amount of expertise and skill, and can be time consuming, depending on the amount of detail required.

VideoTrace attempts to circumvent these barriers by providing a recognisable and direct base from which to model 3D objects - a video. First, the object is filmed (with any type of video camera). The video is then run through a process which analyses each frame of the video and estimates the position of the camera for each frame. The process also outputs a group of 3D points called a "point cloud" which corresponds to features of the object found in the video by comparing subsequent frames and identifying consistent areas.

The user is then able to step through the original video and "trace" features using a set of primitive tools (such as straight lines, curves and polygons). It is this interactive step which provides a more accurate result than a purely automated approach. These approximations, in conjunction with the point cloud and the set of camera positions, allow for the user to build a complete 3D model of the object represented in the video using an intuitive, real-world baseline.

The traditional modelling process

The first step in the ‘traditional modelling’ process is the gathering of reference materials. In this stage, references of the object to be modelled are collected. These can be anything from photos and videos, to blueprints or CAD files. The data collected will allow the modeller to build the 3D mesh more quickly, and with more accuracy.

In the modelling stage, the 3D artist will use the collected reference materials to build a virtual representation of the object. A technique that is often used by a modeller is to bring a blueprint or photo inside the 3D program to use as a guide - Figure 22 and Figure 23.

Using polygon modelling techniques, the modeller will start building the form of the object, moving and aligning points to the reference plane. Through an iterative process the modeller will gradually refine the model, adding and removing details as required. It can be a time consuming process depending on the quality and detail required of the end product. The more detailed the model needs to be, the longer it will take to build. Video game companies developing the latest generation of games often employ very large teams of artists to build assets for this reason.

In the next stage the 3D mesh is prepared for texturing. A technique called "UV mapping" is used to map one or more 2D textures to the mesh's surface. In this process, each vertex of the mesh gets mapped to a 2D coordinate system (UV) which corresponds to the 2D texture map. The 3D artist will use various tools to unwrap and position the faces in this UV space in a coherent manner.

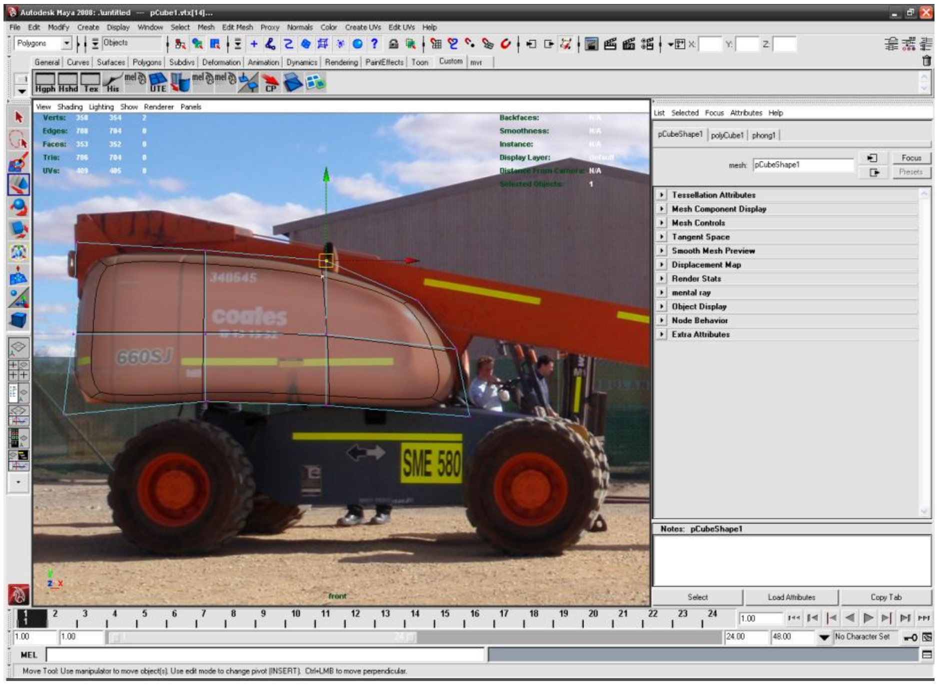

Figure 22. A side view photograph of the object to be modelled can be used as a guide.

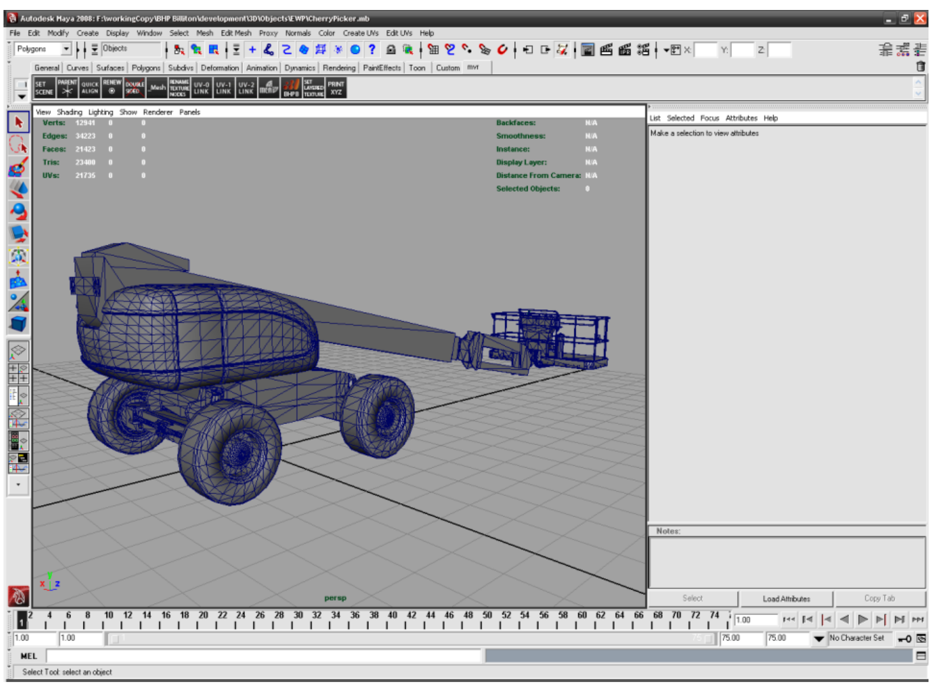

Figure 23. The completed EWP mesh.

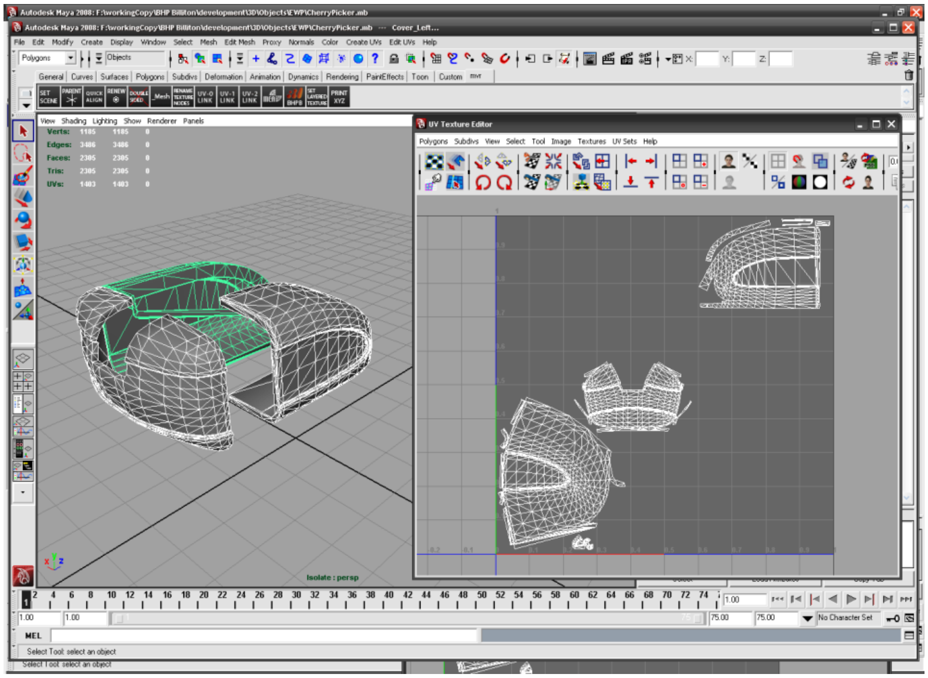

Figure 24. Left: A section of the model in 3D. Right**:** The corresponding mapping in 2D texture space.

The time it takes to complete this task varies considerably depending on the amount of details present in the model. Simple meshes can be unwrapped in a few minutes while some very detailed meshes can take a few hours to map out.

In the final stage, the 3D artist will create the textures using a 2D painting program such as Photoshop. A 2D template of the UV layout will often be rendered out from the 3D program and bought into Photoshop as a guide. Using various tools the 3D artist will add additional details to the mesh which were not modelled in. This can be done either by painting manually or by manipulating photographs to fit inside the UV template. Again this process can take anywhere from few minutes to many hours depending on the requirements.

Traditional 3D modelling requires many skills and techniques and the end result is largely based on how talented the artist is and how much time they have to refine the model.

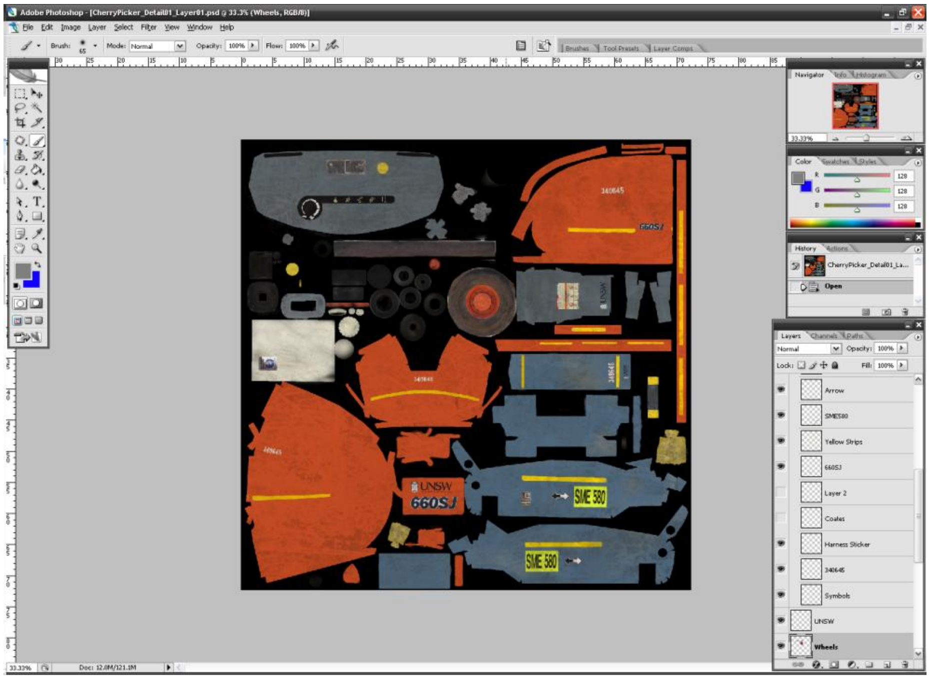

Figure 26. The texture being painted by the artist in Photoshop.

VideoTrace Comparison & Discussion

Ostensibly, the VideoTrace and standard modelling methods differ, but several parallels can be drawn. The filming and tracking stages in VideoTrace are analogous to the gathering of reference materials in standard modelling, as the stages all deal with processing real-world data (photographs and video) in order to assist the modelling process. Of course, in the case of VideoTrace, the real-world data has much more of an active role in the quality of the end result, as the data is used directly by the semi-automated modelling process (rather than being interpreted manually in the case of traditional modelling).

More direct comparisons can be made between their respective modelling and texturing stages. While a traditional 3D modelling package usually offers a wide array of tools with which 3D objects can be constructed and modified, the majority of work is usually performed with a small subset of those tools. VideoTrace's modelling tools (such as the sketch, curve drawing, divide, mirror, extrude and anchor tools), while simplified, are found in one form or another in traditional modelling packages.

The unwrapping and texturing stages of both processes result in the same output - a set of texture coordinates and one or more textures to be mapped onto the object. However, VideoTrace uses an automated method to calculate texture coordinates and texture generation, while the standard modelling method relies on the artist to produce these manually.

The development of an interactive 3D simulation involves the production of many types of 3D models. These range from high-resolution models (which are often the focus of a particular scenario or area in a simulation) to secondary models. These secondary models can range from moderately detailed incidental props which are used to provide medium-range detail to a scene, or sparsely detailed objects which are viewed from a long distance and provide background detail and context to a larger area, such as buildings and structures (Figure 27).

For the purposes of constructing secondary prop models to be shown at both medium and long range distances, we have found VideoTrace to be a reasonable alternative to standard modelling. The scissor lift, forklift and boom lift models developed in VideoTrace were able to be completed rapidly, and when placed in the site model, they were able to contribute to the overall visual fidelity of the scene. Furthermore, although we did not model any of the long-range buildings and structures using VideoTrace, its application in this area is evident, as it would allow for the rapid reconstruction of the actual environment surrounding an area. This would undoubtedly add to the visual fidelity of the scene.

That said, we found that for the purposes of constructing secondary prop models, the VideoTrace method did not offer any substantial advantages over the traditional modelling workflow, and in fact introduced several issues. While the initial construction of the model would be faster, the models themselves required subsequent editing in a traditional 3D package before they were ready for use in the simulation. Objects created in VideoTrace were not scaled consistently with the rest of the scene, so a scaling factor had to be applied. VideoTrace did not support the setting of a "pivot point" for an object, which is a single point that is used by the 3D simulation to determine the position, scale and orientation of the whole object, so this pivot point had to be set manually. We received the first two models in two different file formats (STL and WRL) and each of these introduced errors which required more post-processing on the model to be done. However, the second set of models that we received came in the FBX format, which we were able to import flawlessly. We would expect further development of VideoTrace to fix these problems.

For simulations which centre around a particular object, a high-resolution model of this object is required. Such models usually contain sufficient detail to maintain a high level of visual realism at close viewing distances, and it is in this area which the VideoTrace software is also currently lacking (Figure 28).

Figure 27. VideoTrace models in the distance adds fidelity to the scene

As mentioned earlier the UV unwrapping stage is normally done manually by a 3D artist in a logical way to achieve optimal results. In VideoTrace, this process is automated. This is fine if the texture that VideoTrace produces does not require modifications, but if changes are needed (for example, altering base colours, removing shadows and artefacts, and adding or removing detail such as damage or dirt) then it is extremely difficult to alter (Figure 29). However, VideoTrace's unwrapping system is still an active area of research and development, and allowing the user to control some portion of the unwrapping process (similarly to the modelling process) has been flagged as a potential option. This would undoubtedly alleviate the problem.

The quality of the textures that are produced by VideoTrace is highly dependent on both the quality of the original video source, and how comprehensively the scene was captured. Unfortunately, in the case of the elevated work platform, the vehicle was parked up against a building and unable to be moved, which resulted in a lack of textures on the uncaptured side of the vehicle. Unfortunately, VideoTrace’s Mirror tool was not used to copy the texture from the visible side of the elevated work platform, but this functionality does exist, which does alleviate the problem.

Figure 28. Close-up views of the elevated work platform. Left: Using Autodesk Maya, Right: Using VideoTrace

Figure 29 Left: Texture map generated by VideoTrace. Right: Texture map laid out manually

Another issue we had with the EWP was that the VideoTrace texture generation system does not decouple the "lighting" of the scene from the object's texture, so when the object is imported into a 3D simulation, the lighting will appear to be fixed (regardless of the orientation of the object and the actual lighting in the scene) which leads to an inconsistent look (Figure 30). This problem can be fixed by modifying the texture in a program such as Photoshop, but can be a time consuming process. However, this is definitely an issue which can be solved with further development.

The ability to resolve small-scale texture details (such as signs, buttons and warning labels) is dependent on the resolution of the video camera. This sort of detail is often required of a high-resolution 3D model. Usually, details such as these would be captured close-up using a still camera and then composited into the primary texture, but this task is rendered difficult due to VideoTrace's aforementioned automatic unwrapping.

Figure 30. The above images show two sides of the EWP model created using VideoTrace. Areas which were lacking video footage were unable to be modelled.

Although the modelling paradigm in VideoTrace does cater to those with minimal 3D modelling experience, and is nowhere near as involved as the traditional modelling workflow, it is still a technical process which requires users to invest time in training and experience to achieve the best results. In this respect, it is similar to learning a standard 3D modelling package. However, if a particularly high-resolution model is required (in the area of 10,000 faces), modelling in VideoTrace may prove difficult, due to the absence of certain tools that standard 3D modelling packages contain. (For comparison, the models that were successfully built in VideoTrace are in the area of 1,000-2,500 faces).

Initially, VideoTrace was unable to accurately model features such as pipes and handrails. This was because the feature tracker couldn't sufficiently track thin objects between frames, and subsequently, the automatic 3D modelling could not be applied. Manual intervention was still possible, but this had to be done on a frame by frame basis, which would've been time consuming.

An extension to VideoTrace was developed which allowed the user to specify "snapping" planes in 3D. These planes were defined with respect to existing feature points, and then allowed for objects to be constructed by mapping the user's sketch onto the plane. This improvement resulted in a significant amount of time being saved, even in areas in which the automatic feature extraction had failed, and enabled such handrail-type features (which were present on vehicles such as the boom lift and scissor lift) to be modelled successfully.

VideoTrace has limited support for modelling of objects that require animation. Simple vehicles (those with a body and four wheels) can be modelled and animated by tracing and exporting the wheels independently of the body, but for more complex articulated vehicles (such as the elevated work platform), the model would need to be properly rigged and animated in a standard modelling package.

Currently, the VideoTrace process only supports the usage of a single video sequence. Expanding this to support multiple video sequences would definitely result in higher quality, as the feature tracking stage would be able to capture more features (and hence increase the accuracy of the modelling stage). Also, this would alleviate issues that would arise when a suitable filming path cannot be found due to areas being physically inaccessible. This has been identified as an area for further work.

Implications to using VideoTrace for upcoming VR applications & Conclusion

While the various extensions to VideoTrace have undoubtedly improved its capabilities, it is still limited in its application for the UNSW development team. Though low and medium-resolution objects can be constructed quickly and with sufficient accuracy using VideoTrace, it does not currently offer any substantial benefits over the traditional modelling workflow. Creating high resolution models using VideoTrace is possible but will be a very difficult and time consuming process. Additionally, most models and textures produced by VideoTrace still needs some adjustments by a 3D artist before it can be used in the simulation.

While traditional modelling practices can be time consuming, they are effective in creating highly detailed and efficient models which represents and captures machinery, scenery and images accurately. Including a lesser-quality image can detract from the learning process. The participants of VR Mining modules are experienced and familiar with the machinery, sceneries, equipment and images being modelled. Altering the appearance of any of these items will ultimately result in the learner focusing on the inconsistencies of the model and will likely miss the overall module objectives because of this. High quality images are needed to ensure that learners stay focused and concentrate on achieving the learning outcomes. The development team have determined that the most effective and time-efficient way of creating the necessary models is by using the traditional process.

The time, effort and necessary training required to use VideoTrace means that its adoption is currently not practical if there are capable 3D artists working on the project. However, its potential is obvious, and the development team is committed to its improvement (as evidenced by the extensions applied to VideoTrace after our initial appraisal). We would not hesitate to revisit it in the future, and remain interested in its ongoing development.

8. Educational Evaluation of the Working at Heights Module

Figure 31. First exposure of the apprentices to the simulation.

Under the project, a high quality interactive 3D model was developed. The model focuses on the issues of 'Working at Heights' and covers five areas under the main module as sub-modules. They are, Correctly Erected Scaffold, Incorrectly Erected Scaffold, Open Trench, Light Globe Change Using Ladders and Elevated Work Platform.

The interaction with these modules that the user experience has been derived from site-based documentation and training scenario course materials. As part of the development process it was considered essential that some form of educational evaluation be performed. It was decided that this evaluation should be approached from two aspects.

- Perform an experimental deployment at a site prior to the module being deployed at Olympic Dam Mine site and establish where the simulation module may fit into a training course in any later formal deployment.
- Perform a series of semi-controlled and fully controlled scientific experiments to collect and record data on the module with respect to the module's educational and psychological design aspects. These experiments would look also at potentially

improving the instructional design in the module and establish what user's think of the module.

Thebarton Experimental Deployment

The Working at Heights module had been developed by the technical teams and industry collaborators at UNSW, Uni' of Adelaide and primarily within the BHPB environment and the module had reached a stage where it needed to be evaluated from a usability perspective and educational perspective – that is, where does it fit into the framework of a 'Working at Heights' training session and how do the trainers and trainees feel about the simulation? One of the aims is continual improvement of the module.

The experimental deployment was hosted at Safety and Rescue Training Australia's (SRTA) Thebarton facility and they are gratefully acknowledged for accommodating this experiment. The training experience that SRTA and all the industry collaborators have provided is invaluable in this type of project.

The main objectives of this experiment were to,

- Develop a lesson plan that includes the simulation into a formal training program for Working at Heights. This was performed by former BHPB employees consulting to the project.
- Expose the module in its prototype form to a 'real' audience and provide them with an interactive experience using the simulation.
- Test the usability of the system from a trainer perspective and acquire feed back.
- Test the system from a trainee perspective and acquire feedback.
- Collect data in the following categories.
    - Trainee demographic data.
    - Knowledge transfer.
        - Pre-training knowledge test.
        - Post-training knowledge test.
    - Training feedback.
    - Simulator course material feedback.
    - Trainee's comments on the module.
    - Trainer feedback and future improvements.

To acquire the above datasets, the ‘Working at Heights’ module was installed on a personal computer and the module displayed on a projection screen in a classroom environment. An example image of training underway using the module is shown in Figure 31.

In this instance, the training was performed in the ‘traditional’ format where the trainer was at the front of the classroom and drove the simulation. An issue with this configuration is that when using the module, the trainer unfortunately has their back to the audience which is not the ideal configuration. The preferred configuration is where the trainer sits towards the back of the room and a trainee drives the simulation (Stothard 2008). However, at this stage the aim was to familiarise the trainer and the trainees with a new concept so this was not pursued. Room configuration is a matter for a later project.

The experiment was performed over four days and the ‘Working at Heights’ training session was exposed to a group of 42 apprentices. Simulation formed part of the training process and during the simulation trainees were able to answer questions on the screen via an individual ‘Clickapad’ keypad linked to the trainee’s identity and data record. Their responses were recorded to a database.

The lesson plan that was developed for the training program was very detailed and hence for brevity is located in Appendix. An example section of the lesson plan is shown in Figure 32, where it can be seen that the lesson plan uses a mixture of presentation methods to provide the course material. The approach used to incorporate the simulation into the plan is analogous to that of Schmid and Rossmann (2004), and Arggarwal et al (2006) and McMaster et al (2008),

Data collection was undertaken across the four days. Each day a new group of apprentice trainees participated in a day long training session on safety training relating to ‘Working at Heights’. Five simulator scenarios relating to ‘Working at Heights’ was presented to the trainees across the course of each day (See Lesson Plan Appendix). In this study, the ‘Changing of the Globe’ scenario was selected as the module to evaluate. This was the first of the five scenarios presented to the trainees. Two groups (A: Day 1 and B: Day 2) were exposed to the scenario via the simulator, and two groups (C: Day 3 and D: Day 4) were exposed to scenario via the pre-existing practical training module developed by SRTA.

Training Outcome	Time	Learning Methods	Learning Tools	Refer	
Safety	5	General Evac Procedure Training	Walk Around of Training area		Trainer
Explain the Data/Assessment process	10	Verbal	Sign Consent	HO1	Trainer
Pre Assessment	15	Written	Paper Data	ASS01	BCC
Meet the Group	10	Discussion on groups experience	Name Tags on Tables	STRA	BCC
Learning Outcome 1 Ladders					
The regulations SA OHS Act	10	Verbal	Projector	PP	Trainer
	1	Caution Tape and Danger	Verbal		Trainer
	4	Sign off THA to enter area	Verbal		Trainer
	4	Footing the Ladders	Verbal		
Understanding harness and W@H safety equipment	10	Verbal	Examples of equipment	EXP1	Trainer
Identify the correct use of safety equipment		Verbal	Work through STRA W@H Workbook	WK1	Trainer
Inspections of Safety Equipment		Verbal	Work through STRA W@H Workbook. Real life examples not documented	WK1	Trainer
Protection Falling Objects		Verbal	Guard Rail 550kn can not be used as anchor point. Not documented		Trainer
Use of ladders		Demonstration	Ladders examples in workshop	EXP2	Trainer
Post Knowledge Test		Written	Paper Data	11.4	BCC
Lunch				12.3	
Understanding the consequence?	4	**Sim Module 1 Ladders Run**	Video John Luck	VID1	Sim
The candidate will be able to identify the working site for the simulation		Walk Out around Site	Sims Class Room		Sim
	4	Intro To Ladders	Video John Luck	VID2	Sim
W@H BHPB THA document	4	BHPB THA Question	Click pads Yes or No		Sim
	4	Question on Selection of equipment	Click pads Yes or No		Sim
	4	Permits required for Task	Click pads 1234567		
	2	Limited free fall 600mm	Lap safe System		
	4	PPE Selection	Click pads		Sim
4 to 1 Ratio	4	Adjusting Ladder	Correct View to see measurements		Sim
Play Video	*5*	*Shane working with safety line*	*Identify the safety breach in this video*		
	104				

Figure 31. Example section of lesson plan.

Trainee demographic data

Trainee demographic data was collected prior to the training session commencing. This data was collected to gain an insight into the people that were exposed to the prototype deployment.

Ref	YOB	Gender	Ethnicity	Language	Computer Literacy
A1	65	M	Aust	Eng	2
A2	75	F	Aust	English	2
A3	75	M	Aust	English	2
A4	74	M	Aust	English	3
A5	64	M	Aust	English	2
A6	53	M	Aust	English	2
A7	80	M	Aust	English	3
A8	82	M	Aust	English	3
A9	69	M	Aust	English	2
A10	69	M	Aust	English	3
A11	63	M	Aust	English	5
B1	79	M	Aust	English	5
B2	75	M	Aust	English	5
B3	80	M	Aust	English	5
B4	66	M	Aust	English	4
B5	68	M	Aust	English	5
B6	81	M	Aust	English	5
B7	73	M	Aust	English	4
B8	71	M	Aust	English	5
B9	57	M	Aust	English	5
C1	62	M	Aust	English	5
C2	71	M	Aust	English	3
C3	82	M	Aust	English	3
C4	61	M	Aust	English	1
C5	83	M	Aust	English	3
C6	69	M	Asian	English	2
C7	68	M	Aust	English	3
C8	72	M	Aust	English	5
C9	70	M	Aust	English	2
C10	52	M	Aust	English	5
D1	71	M	Aust	English	4
D2	59	M	Aust	English	4
D3	72	M	Aust	English	4
D4	76	M	Aust	English	4
D5	75	M	Aust	English	4
D6	70	M	Aust	English	4
D7	67	M	Aust	English	4
D8	69	M	Aust	English	4
D9	82	M	Aust	English	4
D10	66	M	Aust	English	4
D11	67	M	Aust	English	4
D12	59	M	Aust	English	4

Table 15. Demographic of the apprentices exposed to the training session.

The demographic of the four groups are shown in Table 15 that shows that the participants were primarily Australian with English as their first language. One female was present. The oldest apprentice was 57 years with the youngest being 26 years. The median age across the four groups was 39 years.

The computer literacy that each individual reported across the groups ranged from 5 out of 5 to 1 out of 5. The median computer literacy was 4 out of 5. Table 15 suggests that the majority of the group of apprentices would likely have no problem understanding the text and verbal based instructions within the simulator and also the concept of using a computer for training purposes. However, if the module was used to train non-English speaking people from a different cultural background, it is fair to say that the module would need to be tailored to their language and the method of communication of ideas within the simulation may be actually be different.

Knowledge transfer test.

Before undertaking the training, each participant was asked to complete a pre-training knowledge test on the safety issues surrounding ladders and changing of a globe. Following the training, they were asked to complete a post-training knowledge test. An example of the pre-training (and post-training knowledge) questionnaire is shown in Appendix.

The results of the pre-training and post-training knowledge tests are presented in Tables 16 and 17 and Figure 32 and 33 and show that their has been an increase in knowledge for 38 out of the 42 trainees with respect to the learning outcomes of the “light globe change using ladders” scenario across the Simulation groups A and B and the PowerPoint groups C and D.

‘Simulation’ pre and post knowledge tests

In the pre-knowledge test in Simulation groups A and B, the maximum scored by a trainee was 87.5%. The minimum scored by a trainee was 37.5%. The average score of the two groups was 52.50%. The modal score was 43.75%

In the post-knowledge test in Simulation groups A and B, the maximum scored by a trainee was 87.5% (but not the same person). The minimum score by a trainee was 56.25%. The average score of the two groups was 71.56%. The modal score of the two groups was 75%

The maximum improvement shown by a trainee in the Simulation groups was 43.75%, the minimum improvement shown by a trainee was -12.5%. The average increase was 19.06% and the modal increase was 31.25%.

The data show that the trainees have slightly improved their knowledge through the simulation training session as would be expected. However, it is unclear if this is due to the simulation at this stage as the simulation is part of the lesson plan. Also, none of the trainees attained 100%, the modal increase was 31.25% and this may not show a sufficient transfer of knowledge through this method of training (also refer to Trainer Comments later in this section). Two of the 20 participant received ‘negative’ training – that is, their scores were worse in the post-knowledge test. This was subject A11 and B2 who had a high computer literacy. Why this is, is not known at this stage.

‘PowerPoint’ pre and post knowledge tests

In the pre-knowledge test in PowerPoint groups C and D, the maximum scored by a trainee was 68.75%. The minimum score by a trainee was 6.25%. The average score of the two groups was 44.74%. Modal score was 62.5%.

In the post-knowledge test in PowerPoint groups C and D, the maximum scored by a trainee was 87.5%. The minimum score by a trainee was 31.25%. The average score of the two groups was 16.48%.

The maximum improvement shown by a trainee in the PowerPoint groups was 50%, the minimum improvement shown by a trainee was -12.5%. The average increase was 16.48% and the modal increase was 25.0%.

The data show that the trainees have slightly improved their knowledge through the PowerPoint training session as would be expected. However, it is unclear if this is due to the PowerPoint at this stage. Also, none of the trainees attained 100%, the modal increase was 25% and this may not show a transfer of knowledge through this method (also refer to Trainer Comments later in this section). Three of the 20 participant received ‘negative’ training – that is, their scores were worse in the post-knowledge test. This was subject D4, D10 and D12, who had a relatively high computer literacy. Why this is, is not known at this stage.

Group	Pre-training Knowledge (16)	Percent	Post-training Knowledge (16)	Percent	% Increase in knowledge following training
A1	13	81.25	13	81.25	0
A2	7	43.75	9	56.25	12.5
A3	9	56.25	10	62.5	6.25
A4	8	50.00	10	62.5	12.5
A5	8	50.00	12	75	25
A6	6	37.50	11	68.75	31.25
A7	7	43.75	14	87.5	43.75
A8	7	43.75	12	75	31.25
A9	9	56.25	12	75	18.75
A10	7	43.75	11	68.75	25
A11	14	87.50	12	75	-12.5
B1	8	50.00	13	81.25	31.25
B2	10	62.50	9	56.25	-6.25
B3	7	43.75	10	62.5	18.75
B4	6	37.50	10	62.5	25
B5	8	50.00	12	75	25
B6	9	56.25	11	68.75	12.5
B7	9	56.25	14	87.5	31.25
B8	7	43.75	12	75	31.25
B9	9	56.25	12	75	18.75
		%		%	%
Maximum	14	87.50	14	87.5	43.75
Minimum	6	37.50	9	56.25	-12.5
Median	8	50.00	12	75	21.875
Average	8.40	52.50	11.45	71.56	19.06
Mode	7	43.75	12	75	31.25

Table 16: Data from pre and post knowledge tests Group A and B (Simulation).

Group	Pre-training Knowledge (16)	Percent	Post-training Knowledge (16)	Percent	% Increase in knowledge following training
C1	8	50.00	14	87.5	37.5
C2	8	50.00	13	81.25	31.25
C3	7	43.75	11	68.75	25
C4	10	62.50	13	81.25	18.75
C5	10	62.50	14	87.5	25
C6	1	6.25	7	43.75	37.5
C7	9	56.25	13	81.25	25
C8	4	25.00	8	50	25
C9	3	18.75	7	43.75	25
C10	10	62.50	11	68.75	6.25
D1	8	50.00	9	56.25	6.25
D2	7	43.75	9	56.25	12.5
D3	10	62.50	11	68.75	6.25
D4	9	56.25	8	50	-6.25
D5	9	56.25	10	62.5	6.25
D6	5	31.25	8	50	18.75
D7	11	68.75	13	81.25	12.5
D8	5	31.25	13	81.25	50
D9	5	31.25	8	50	18.75
D10	7	43.75	5	31.25	-12.5
D11	11	68.75	13	81.25	12.5
D12	10	62.50	7	43.75	-18.75
		%		%	%
Maximum	11	68.75	14	87.5	50
Minimum	1	6.25	5	31.25	-18.75
Median	8	50.00	10.5	65.625	18.75
Average	7.59	47.44	10.23	63.92	16.48
Mode	10	62.50	13	81.25	25

Table 17: Data from pre and post knowledge tests Group C and D (PowerPoint).

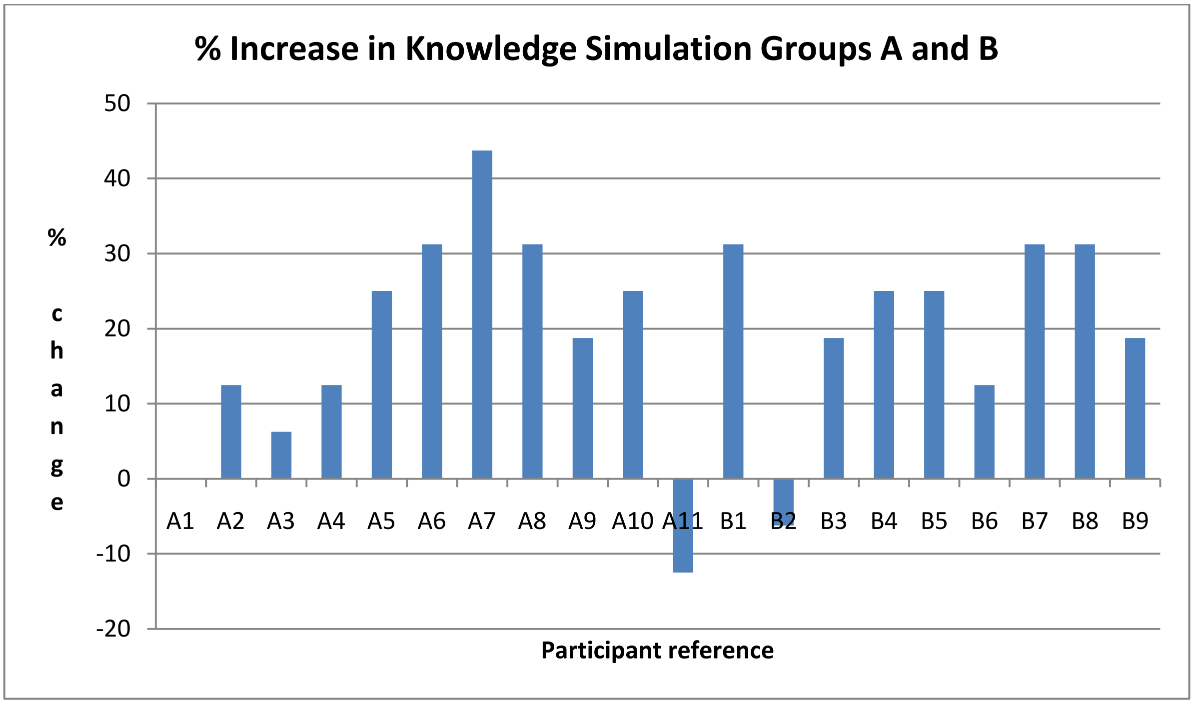

Figure 32. Percentage increase in knowledge following training (Simulation).

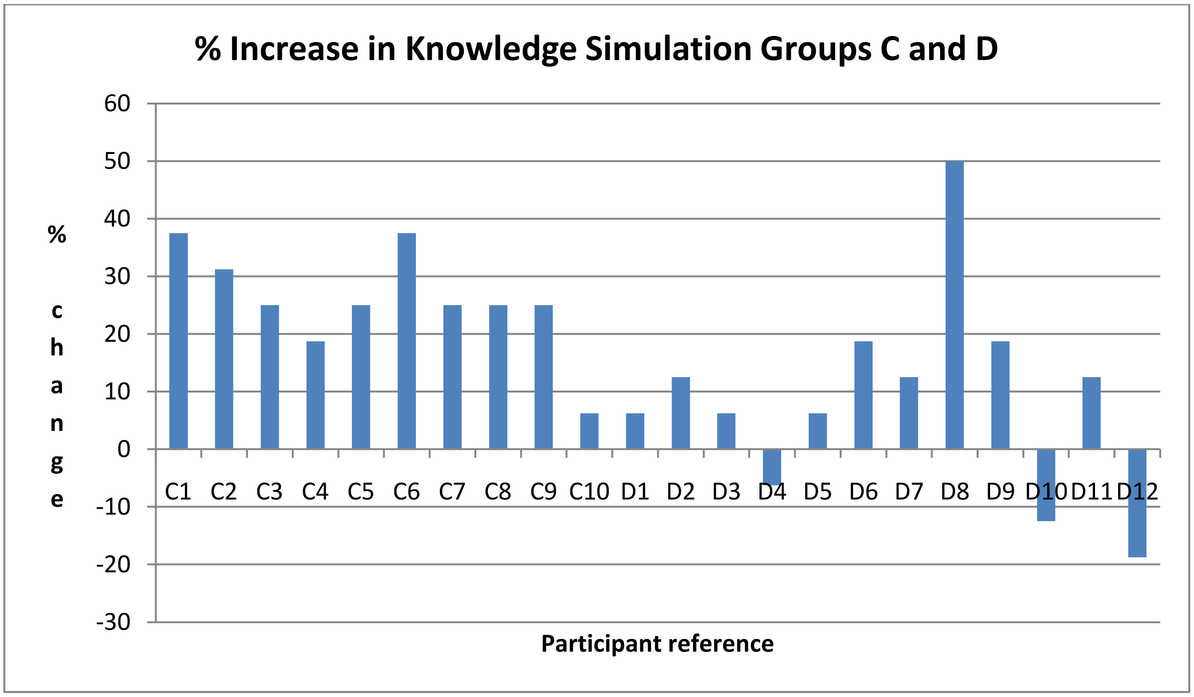

Figure 33. Percentage increase in knowledge following training (Simulation).

Discussion of the pre and post knowledge tests

In both the Simulation groups A and B and the PowerPoint groups C and D, there was a slight increase in the knowledge between the pre-knowledge test and the post-post knowledge test. The increases were 19.06% and 16.48% respectively. This is only a very small increase and may not be due to the Simulation or the PowerPoint at this stage. It may be a result of, the trainer, group dynamics, the simulation, the PowerPoint, engagement, no-consequences for failure, boredom – five people attained negative scores, and so on. However, it shows that somewhere there has been an improvement and transfer of a small amount of knowledge – but this is a broad assumption. Of concern, is that in both the Simulation group and the PowerPoint groups, five people received ‘negative training’ and their scores were worst after training. A further concern is that three of the five were in PowerPoint Group D. Where-as with the Simulation groups, the two people that experienced ‘negative training’ occurred one in Group A and one in Group B. This could be again be due to, different trainers, group dynamics, etc, etc and demonstrates a need to control all variables when performing experimental analysis and keeping trainees engaged in their training.

Training Feedback

To acquire some training feedback, the trainees were asked to complete a training questionnaire. The questionnaire is shown in Appendix and asks questions on the Trainer/Facilitator, Programme Content, Course Material, Overall and finally Trainee’s Comments. Table 18 shows the score relating to Trainer/Facilitator, Programme Content and Course Materials and Overall.

The above relates to the course overall and it can be seen that the Trainer ranks highest with Material and Programme Content next and finally Overall generally ranking lowest toward the “Neither Agree or Disagree” part of the scale. The impact of simulation is difficult to ascertain as the questions that relate to it are lumped in with ‘Course material’. A clearer interpretation that focuses on the simulation follows in the next section.

Simulation Feedback from Trainees

To acquire some feedback from the trainees, they were asked to complete a questionnaire containing some questions relating to the simulation. Trainees from both simulation and PowerPoint Groups answered these questions. That is, the questionnaire related to the simulation during the whole course and all the simulation components and not purely the light globe using ladders scenario. The scores were based on a Likert Scale where 1 = strongly disagree and 5 = strongly agree.

Group A	Facilitator	Content	Material	Overall	Group C	Facilitator	Content	Material	Overall
A1	4	3.7	3.7	4	C1	4.5	3.5	2.3	4
A2	3.9	3.7	3	4	C2	5	4.5	4	4
A3	3.9	3.9	3.9	4	C3	4.5	4	3.4	4
A4	5	4	3.9	4	C4	4	3.4	3	4
A5	4.2	3.9	4	4	C5	5	2.5	5	5
A6	4.5	3.4	4	4	C6	5	4.5	3.4	4.5
A7	4.5	4	3.4	3.7	C7	5	5	4.5	5
A8	5	5	4.5	4	C8	5	5	4	4.5
A9	4.5	3.4	4	4	C9	5	5	3.5	5
A10	4	3.4	4	4	C10	4	4	4	4
A11	4	4	4	3.7					
Average	4.32	3.85	3.85	3.95	Average	4.70	4.14	3.71	4.40
Group B	Facilitator	Content	Material	Overall	Group D	Facilitator	Content	Material	Overall
B1	3.4	4	4	3.7	D1	3.4	4	4	3.4
B2	4.5	4.5	3	2	D2	4	4	3	2.3
B3	5	3	4	2.5	D3	5	5	5	4.5
B4	5	5	5	4	D4	4	4	4	4
B5	4.5	3.4	3.4	3.4	D5	4.5	4	4.5	4
B6	5	5	5	4.5	D6	4.5	4	4	4
B7	5	5	5	5	D7	4	4	3.4	3.4
B8	4.5	4.5	5	4	D8	4	4	4	4
B9	4.5	4.5	4.5	4	D9	4.5	4	4.5	4
					D10	4	4.5	5	3.4
					D11	4	4	4	4
					D12	4	4	4	4
Average	4.60	4.32	4.32	3.68	Average	4.16	4.13	4.12	3.4

Table 18 Training Feedback Results.

		Learning Interactive	Attention Grabbing	Easy to Follow	Control Sim Myself	Prefer Standard Training
Group A	Average score on Likert scale	3.45	3.36	3.91	3.36	2.91
Group B	Average score on Likert scale	3.33	3.44	3.67	4.00	3.11
Group C	Average score on Likert scale	3.7	3.5	4	4.6	2.9
Group D	Average score on Likert scale	3.42	3.42	4.00	3.58	2.73
Average over all groups		3.48	3.43	3.89	3.89	2.91

Table 19. Simulation Feedback from trainees.

Table 19 shows, that for the questions relating to the simulator,

1. "Learning through the interactive simulator was enjoyable?" Across the entire group the average was 3.48 which is halfway between *Neither agree or disagree* and *Agree*. That is, barely positive.
2. "The simulator training was attention grabbing?" Across the entire group the average was 3.43 which is almost halfway between *Neither agree or disagree* and *Agree*. That is, barely positive.
3. "It was easy to follow what was being taught by the simulator?" Across the entire group the average was 3.89 which is just over halfway between *Neither agree or disagree* and *Agree*. That is, almost positive.
4. "I would have preferred to control the simulator myself?" Across the entire group the average was 3.89 which is just over halfway between *Neither agree or disagree* and *Agree*. That is, almost positive.

5. "I prefer standard training over simulator training?" Across the entire group the average was 2.91 which is, just over halfway between Disagree and *Neither agree* That is, almost negative.

The data collected relating to the simulator show that the apprentices only slightly preferred the simulator when presented in the training session format performed at Thebarton. They also only slightly preferred it to standard training on this occasion. In future experiments, it would be pertinent to focus directly on the simulation when collecting feedback as the data is difficult to accurately assess due to unknown variables mentioned previously. The key one is probably engagement.

Trainee's comments

The trainees were asked to comment on the training. The questions were as follows with the responses. Their responses to the question are summarised to show the range of answers.

1. "If you disagreed with any of the statements above, it would be appreciated if you could tell us why?"

- Q1,Too much like play station,
- Q1 Sim was slow and real scenario would be more understanding in a real environment,
- Q1 Practical on scissor lift to break up theory,
- Q1 Simulator was better to see everything in depth of field
- Q1 Simulator needs more improvement,
- Q1 Not self controlling
- Q1 Try the sim yourself,
- Q1 Better to use sim yourself,
- Q1 Questions in questionnaire weren't easy to understand,
- Q1 Simulator training is interesting but would have been better if I had a go,
- Q1 Would have preferred standard & simulation for 1 day each,
- Q1, Gave you more of a real scenario feel
- Q1 More handouts,
- Q1 Simulator makes you feel safe but can give you a false sense of security if you have a heights problem,
- Q1 Would have preferred to read a book then answer some questions
- Q1 Need to sort out program
- Q1 Some of the questions were relevant
- Q1 Glitches with software, would have liked to explore and control the environment myself

The responses for question 1 show that the apprentices would prefer to have ago on the simulator themselves and possibly for it to be longer. They thought the simulation needed some improvement but was quite real. The questionnaire questions were not easy to understand and may reflect the use of text based media. A couple of people wanted more handouts….?

2. "What did you find to be the most useful aspect of this training - why?"

- Q2, Relevance to P/Safety and corresponding work area.
- Q2 Verbal questions force us to listen more.
- Q2 Using Harness.
- Q2 Harness using it.
- Q2 Harness usage.
- Q2 Types of safety.
- Q2 Knowledge of safety precautions and equipment.
- Q2 Putting harness on should use one on one.
- Q2 Practical on harness.
- Q2 Procedures done on OD safety.
- Q2 About equipment available for use,
- Q2 Practical knots and setting up harness,
- Q2 practical hands on engaging activities relevant,
- Q2 Practical aspects it is what is required
- Q2 Safety procedures
- Q2 Video game,
- Q2 Yes,
- Q2 I increased my knowledge about working at heights
- Q2 Learn more about safety,
- Q2, P/Safety and relevance of it,
- Q2, How to use a ladder 4:1 and 3 contact climbing,
- Q2, Using Equipment,
- Q2 Safety aspects
- Q2 The physical doing of placing on the harness because it is something that will stay in your memory rather than watching a computer program do it.
- Q2 Knowing that I had to be harness in most situations,
- Q2 The amount of safety provided.
- Q2 Learning how to set up and use harness.
- Q2 Feed back from trainer.
- Q2 The whole course gave you a real look at what is expected of you.
- Q2 All the practical side hands on learning.
- Q2 Was all relevant and useful to know.
- Q2 Safety eye opener.
- Q2 I enjoyed the simulator training and the practical.
- Q2 Sim providing the visuals aspects to scenarios.
- Q2 Being able to identify hazard you normally would let slip.
- Q2 Identifying hazards and appropriate PPE as it will help out in the workforce.
- Q2 Practical examples in workshop to see it first hand.
- Q2 Practical on safety harness hands on practs is good you remember.

The trainees particularly like the practical and hands on training part of the course, particularly the harness and using the equipment. This makes sense as these are practical people. The simulation should probably be practical and hands on too.

3. "Was the Virtual Reality Training method compatible with your learning style and preference?"

- Q3 No was not realistic enough for me,
- Q3 Yes,
- Q3 Yes,
- Q3 Yes,
- Q3 Yes,
- Q3 OK
- Q3 Yes,
- Q3 Yes,
- Q3 Will improve in time,
- Q3 OK
- Q3 Yes,
- Q3 No,
- Q3 Yes but needs to be tidied up
- Q3 OK but done in group isn't preferred, individually would be better.
- Q3 Yes,
- Q3 Yes
- Q3 Yes because it allows you to see how things should be done.
- Q3 Yes,
- Q3 Yes,
- Q3 Yes
- Q3 Yes lecture and reference material
- Q3 Yes as it displayed a working area
- Q3 It was different
- Q3 No took longer
- Q 3 Yes More of a real feel to it

- Q3 It was good and something different
- Q3 Yes,

The feedback for whether the virtual reality simulation was compatible with the trainees learning style was yes. Individual simulator training would be preferred by at least one trainee. Realism was commented upon too.

4. “Did the simulator test your pre-existing Working at Heights knowledge?”

- Q4 To some degree,
- Q4 Yes,
- Q4 Yes,
- Q4 Yes,
- Q4, Yes,
- Q4 Yes,
- Q4, Little
- Q4 Yes,
- Q4 Yes,
- Q4 Yes,
- Q4 Yes,
- Q4 Yes,
- Q4 Yes
- Q4 Yes,
- Q4 Yes
- Q4 A little,
- Q4 Didn't test it but expanded my knowledge,
- Q4 Yes,
- Q4 Yes,
- Q4 Had not previous experience
- Q4 Yes and No
- Q4 No I did not have any to start with
- Q 4 Yes had no knowledge prior
- Q4 Yes
- Q4 Yes
- Q4 Yes
- Q4 No
- Q4 Yes,
- Q4 Didn't really have any

The feedback for whether the simulation tested the trainee’s Working at Heights knowledge was yes. A couple of people realised it needs improvement and others remarked that they had no prior knowledge of Working at Heights.

5. “Do you think the simulator increased your working at heights knowledge?”

- Q5 No knowledge was from paper handouts,
- Q5 Yes,
- Q5, Yes,
- Q5 Yes
- Q5 Yes,
- Q5, Little,
- Q5 Yes,
- Q5 Yes,
- Q5 Yes, standards for tasks,
- Q5 Yes,
- Q5 Yes,
- Q5 Yes,
- Q5 Yes,
- Q5 Yes
- Q5 Yes
- Q5 To see 360 deg mine site
- Q5 A little
- Q5 Yes,
- Q5 Yes
- Q5 Yes it was a good tool for the trainer to reinforce what he already had told us.
- Q5 Yes,
- Q5, When re-fined it could
- Q5 A bit
- Q5 Yes
- Q5 Yes
- Q5 More practical would have helped
- Q5 Yes,

The feedback for whether the simulation increased the trainee's working at heights knowledge was a yes. Some only thought that they a increased little. A comment was made on it being a good tool for the trainer to reinforce a subject.

6. "Please describe your favourite part of the simulator training."

- Q6, It was not too realistic,
- Q6 Tried to place you in scenario safely,
- Q6 Outlay of OD,
- Q6 Practical,
- Q6 None,
- Q6 Participation
- Q6 Setting up the required
- Q6 Interaction
- Q6 Moving around controlling objects,
- Q6 Teething Problems with questions and system.
- Q6 Visually see the area from a differ view
- Q6 The detail of backgrounds,
- Q6 EWP and Boom lift operation
- Q6,Realistic look at the type of tasks that will be required
- Q6 Nothing I thought it was a bit boring,
- Q6 Don't find any,
- Q6 Zoom feature
- Q6 The questions using the key pad
- Q6 All was good
- Q6 All good
- Q6 Answering the questions
- Q6 The accurate portrayal & conditions at Olympic Dam
- Q6 Its ability to highlight areas
- Q6 All of it VR was as if you were there.
- Q6 Understanding of what is required at mine site.

From this question, the trainees seemed to like visual aspects of seeing the mine site and understanding the context of the subject matter. Interaction and answering questions is commented. Generally, they seemed to think it was good.

7. Please describe your least favourite component of the simulator training

- Q7 Answers to question did not correspond,
- Q7 Too slow not realistic,
- Q7 How slow it was.
- Q7 Slow moving could be quicker.
- Q7 Theory,
- Q7 speed of movement,
- Q7 Slow at times,
- Q7 The set up in Uni NSW sounds good.
- Q7 Not individually operated, too slow
- Q7 Did not get to use it.
- Q7 Repeat PPE question all the time.
- Q7 For the students to do more one on one.
- Q7 Repeating the same questions over and over.
- Q7 It would have been good to have a PC ourselves so that we could do the scenarios individually.
- Q7 The questions on the screen did not help us if we didn't do the simulations ourselves.
- Q7 Bit slow and boring,
- Q7 Made things easier could you could see the situation
- Q7 Windows in the way.
- Q7 Slowness and repeated question
- Q7 Too Slow moving could not move back and forward through the exercise well enough
- Q7 Would have liked more hands on training
- Q7 The simulator itself
- Q7 Paper work
- Q7 All of it
- Q7 Slowness, glitches and freezes
- Q7 Questions format on PPE section

- Q7 Presented on a flat screen

This question asks the trainees what they didn't like and clearly, they found the simulation too slow when operated by the trainer. Some of the functional processes like the image being obscured by the dialogues relate to the flat-screen implementation and can be changed. Repetition in the questions was not popular either. The trainees would like to operate the simulation themselves.

8. "What changes would you like to see made to the Virtual Reality component of the training program?"

- Q8 Less Animation more realism.
- Q8 The operator can move sideways.
- Q8 Faster.
- Q8 Quicker Simulation.
- Q8 Need ability to go back to screens,
- Q8 Change the way the multiple answer questions are answered.
- Q8 I expected a 3D walk in Studio and real footage.
- Q8 Wrap around screens.
- Q8 Individual programs loaded on a computer.
- Q8 Faster.
- Q8 Hands On
- Q8 A few more scenario's
- Q8 Able to see work site with questions to one side
- Q8 More flexibility
- Q8 Get rid of it
- Q8 Remove the VR and use a book
- Q8 Specific areas maybe singled out
- Q8 More action on the work site
- Q8 Would like to drive it myself
- Q8 Prefer photos (real life)
- Q8 More hands on
- Q8 Glitch free software

The changes that the trainees would like to see are more realism, a quicker simulation, larger screens and possibly loaded on individual computers. The trainees would also like to see the simulator set up so that they can drive it themselves.

9. Can you offer any suggestions for improvement to the training course in general?

- Q9 Larger screen size would make it more realistic
- Q9 Controls for simulator should be the same as a machine not a joy stick.
- Q9, More info shorter time done at workplace.
- Q9 Could be a 2 day course and more practical.
- Q9 Got slightly boring towards the end could be more interactive some-how, all we did was the group training.
- Q9 No
- Q9 More Practical, great presentation but would have enjoyed it more if I did something
- Q9 Go back to the old school method. (Might be candidate B3)
- Q9 Could be longer
- Q9 No its good
- Q9 More action scenario's maybe show what goes wrong if you don't follow procedures
- Q9 Real life conditions
- Q9 IT guys should do the course the course & understand it
- Q9 Maybe more practical but overall very good.
- Q9 Students to operate simulator.

From this question, the consensus seems to be that a larger screen-size would make it more realistic and also the trainees should interact with the simulation themselves. The consequences of incorrect actions, is also considered important by one trainee.

The trainees provided some useful comments relating to the Working at heights course and it is clear that these people are practical and want to do practical things. The transfer of knowledge during the session is a concern, but it must be remembered that this was the first iteration and the idea was to test the process and the training session format and the way that the simulation was presented was probably not ideal. The responses relating to the simulation suggest that the trainees want to use the system themselves and perform practical tasks within it. When sitting and observing the simulation, they found the simulation to be too slow and in some cases boring. The need for them to interact and engage with the material is extremely important.

Trainer feedback and future improvements

During the course, the trainers reviewed the module and provided some comments and recommendations on the simulation usability and content. The comments are shown in Appendix and many reflect what the trainers would like to see in the simulation. Many of these comments were implemented by the development team following the training session, however, due to budget restrictions; some will have to be implemented in any subsequent project. Some of the feedback relates to usability issues such as joystick controls and the like which were comprehensive and difficult to remember without a sheet with the controls being used. Also, issues such as objects on the screen being obscured by dialogue boxes and the like relate to screen size and module objectives. These are easily altered.

What can be noted from the comprehensive comments is that much focus is placed on making the rules, procedures and assessment processes accessible from within the simulation and adding extra layers to the simulation as though the trainer would lead the trainees around the site. Some of these improvements are implemented in the module; however, what is not clear from these modifications is the instructional design or learning objectives or how formal assessment of the trainees will occur. Again, this is a process for any next project.

9. Educational Evaluation of Working at Heights Module at UNSW

Critical Review: Evaluating Virtual Reality Learning in a Mining Context

Virtual Reality (VR; also known as artificial reality) is a cutting- edge technology that provides three dimensional spatial environments through advanced forms of computer graphics. In essence, the conventionally held view of a VR environment is one in which the participant is completely immersed in, and able to interact with a completely synthetic world. These "fully immersive" VR environments are based on helmet-mounted or immersive display technologies, whereby images are generated in relation to where the user looks and moves. However, the VR label is also frequently used in association with environments where total immersion does not apply. These low immersive VR (or desktop VR) environments typically allow the user to interact with the computer generated images using a computer display and speakers (Inoue, 2007). Learning environments with no immersion on the other hand involve the visual display of material in static form (such as text and illustrations).

VR Training

VR covers a wide spectrum of applications and within the education realm its popularity continues to soar. While VR research is a relatively young field, many within the community state that there are a number of characteristics unique to VR environments (VREs) which have the potential to offer superior learning experiences (Dalgarno, Hedberg & Harper, 2002). These characteristics include (1) immersion; (2) presence; (3) fidelity; and (4) learner control. These characteristics are typically not evident in more traditional learning environments such as lecture oriented classes and interactive demonstrations. It is important to note that throughout this review, the term 'learning' will encompass advances made to skills, knowledge, or attitudes from the VR training. In addition in parts the review will also refer to trainee reactions and transfer of knowledge. While reactions relate to participants perceptions of instructional platforms, transfer is defined as the application of knowledge, skills and attitudes acquired during training to the environment in which they are normally used (Muchinsky, 1991).

Immersion

Witmer and Singer (1998) define immersion as a psychological state in which one perceives to be included in and interacting with an environment of continuous stimulus and experience. However, immersion can also be an objective description of what a particular

VR system provides (Slater & Wilbur, 1997). As mentioned above VR systems are often categorised in relation to the level of immersion they bestow. For instance, immersion can be thought of as the extent to which computer displays are “capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of the human participant” (p. 601, Moreno & Mayer, 2002). Immersion is said to be influenced by a number of factors, including isolation from the physical environment, perception of self inclusion in the VE, natural modes of interaction and control and perception of self-movement.

Presence

Presence is often considered an increasing function of immersion, whereby learning environments with higher levels of immersion induce a higher sense of presence (Barfield & Hendrix, 1995; Witmer and Singer, 1998). Presence is defined as the subjective experience of being in one environment, when situated physically in another. In VRE’s, this refers to experiencing the computer-generated environment, rather than the actual physical scene. A number of factors have been proposed to account for the strength of presence. These are generally categorised into control, sensory, distraction and realism factors (Witmer and Singer, 1998; see Table 20).

Within VR research conflicting arguments have arisen in relation to the influence of immersion and presence on learning. The fundamental argument for immersive learning is that higher levels of immersion promote a higher sense of presence thus creating more engagement and deeper learning. Within VR research conflicting arguments have arisen in relation to the influence of immersion and presence on learning. The fundamental argument for immersive learning is that higher levels of immersion promote a higher sense of presence thus creating more engagement and deeper learning. Arguments based on interest theory of learning (Dewey 1913, as cited in Moreno & Mayer, 2002) state that a stronger sense of presence in the immersive environment allows the learner to become more motivated. This motivation then causes the learner to work harder to learn, resulting in deeper cognitive processing of the material. For instance, Smith & Woody (2000) found that in comparison to traditional lecture oriented classes, multimedia approaches to be better liked by students and yielded improvements in student learning as measured by both student self report and objective outcome testing. In addition, Rose (1995) found that VR promoted more learner attention, motivation and engagement, which could be helpful to promote skills and knowledge of the learner

Control Factors	*Sensory Factors*	*Distraction Factors*	*Realism Factors*
Degree of control Immediacy of control Anticipation of events Mode of control Physical environment modifiability	Sensory modality Environmental richness Multimodal presentation Consistency of multimodal information Degree of movement Perception Active search	Isolation Selective attention Interface awareness	Scene realism Information consistent with objective world Meaningfulness of experience Separation anxiety/disorientation

Table 20. Witmer and Singer's (1998) Four Factors that Contribute to a Sense of Presence.

Arguments in support of VR in a learning context have also centred around certain aspects of cognitive load theory. Certain theorists state that by making the interaction with technology more natural, immersive learning environments might lead to a reduction in cognitive load (Wetzel, Radke & Stern, 1994). For instance, according to Chen (2006) VR technologies enable learner to interact with their learning environment with their hands and body and this "sensorimotor feedback" enhances learning experience. In addition, research has found that by providing richer perceptual cues through a multisensory mode of presentation (i.e. sensory, audio and haptic), the more likely training will be transferred to real world (Jonassen, Peck & Wilson, 1999). Furthermore, Hoffman, Prothero, Wells & Groen (1998) argue that in more immersive environments, the learner's limited attention resources are focused on the content rather than the system interface. As a result, such encouraging findings have often hastened the adoption of these technologies.

While many researchers believe that the higher the immersion the more effective the training, this view is not held by all. According to interference theory, due to the abundance of extraneous materials, highly immersive environments may overload the learner. As found in Moreno and Mayer (2000), additional materials which are unnecessary to making the lesson comprehensible reduces the capacity of working memory and thus interfere with the ability to learn the core material. Researchers also state that reflection may be affected by highly immersive learning environments. According to Norman (1993), dynamic and continually present environments create a cognitive need for event-driven processing. This in turn creates a lack of sufficient mental resources for the concentration required for reflection and processing of the task at hand.

As evident above inconsistency exists within the literature sounding the impact VR training has on learning. Findings from Moreno and Mayer (2002), support this discrepancy within the research. While students who learned in more immersive VREs felt a higher level of presence, this did not lead to an increase or decrease in learning outcomes. These results are neither consistent with the view that highly immersive environments promote interest and effort in learning, nor that highly immersive environments impede learning.

Fidelity

In this context fidelity is defined as the degree to which the virtual environment emulates the real world. The term encompasses physical fidelity (the degree to which the physical VRE looks, sounds and feels like the operational environment); the functional fidelity (the degree to which the VRE acts like the operational equipment in reacting to tasks executed by the trainee); and psychological fidelity (relates to presence, and examines the degree to which the simulation replicates the psychological factors (i.e. stress, fear) experienced in the real world environment. Many VR researchers such as Dion, Smith and Dismukes (1996) believe that the closer the fidelity between the VR system and the environment, the more effective the instruction and the more people will learn.

While in the past the VR community typically assumed the more realistic the better, many researchers now state that simplified, relatively idealized representations are useful for distilling a situation to its essence (Goldstone 2005; Smith 2003)**.** For instance**,** studies have found no differences in learning performance between high and low fidelity training (Taylor et al (1993); Lintern et al, 1987; as cited in Salas et al, 1998; Moroney & Moroney, 1993), and in some cases more effective transfer of learning in low fidelity training (Taylor et al (1991), as cited in Salas et al, 1998; Beringer 1994, Dennis & Harris 1998). Researchers have suggested that VR may not lead to an increase in learning or transfer of knowledge due to the absence of surrounding context. For instance many real-world environments will evoke levels of stress and arousal that may not be directly replicable in VR environments (Driskell, Johnston & Salas, 2001). In summary, Jentsch and Bowers (1998) stress that

VRE's are best designed when only the appropriate details are embellished to increase realism. Thus if the level of fidelity captures the significant elements of the skills or tasks, that level of fidelity is sufficient even if it deviates noticeably from the real world.

Control

In VR educational settings, user control and manipulation has also been found to influence learning outcomes. As highlighted above, control is also one factor that influences the level of presence experienced by the learner. Many expert educational theorists believe that active learning (student-centred) processes are superior to passive (teacher-centred) modalities. Within VR training, active lessons enable students to individually interact with 3D models and control the presentation of learning materials. In contrast passive lessons provide learning materials to students through expert (i.e. teacher) presentations in group settings. In relation to active learning in VR settings, some researcher state that people learn best in an unguided or minimally guided environment (generally defined as one in which the learner must discover or construct essential information for themselves). For instance, many studies within VR research have found active learning to lead to significantly better visual recognition of studied objects when compared to the passive presentation of equally sophisticated 3D virtual objects (James, Humphery & Vilis, 2002; Christou & Bulthoff, 1999). However, others researchers such as Phelps, Fritchle and Hoffman (2004) have found active and passive VR lessons to be comparables in terms of recall and retention of the objects studied. The researchers discussed that this finding could be attributed in part to the "active" group receiving less structured lessons and thus exploring topics not tested or alternatively missing key elements altogether.

Furthermore some researchers have found minimally guided instruction less effective and efficient than instructional approaches that place a strong emphasis on guidance. For instance, Chen, Toh and Ismail (2005) highlighted the potential pitfalls in active VR learning by comparing VR exploration in both guided and non-guided settings. Chen and colleagues (2005) found that when navigation aids (specifically directional arrows) were included (guided exploration) learners outperformed those without navigation aides (non guided exploration). Without guidance the researchers believed working memory became overloaded. As navigation in VR can be challenging the efforts to stay orientated may impose an increase in extraneous cognitive load. Thus, the researchers suggested that instructional materials such as navigational cues can mitigate the amount of mental resources used to deal with extraneous cognitive load, thus leaving more resources for intrinsic cognitive load. In addition, Kirschner, Sweller and Clark (2006) found similar results, and highlighted that the advantage of guidance only begins to decline once the learners have adequately high prior knowledge to provide internal guidance.

Related to user control is the issue of social context within the training environment. Often examined is whether learning is more conducive to small group settings (i.e. two or more students per computer working on the same task in a face to face setting) or alternatively to individual settings (i.e. one computer per student each working on their own task). Several theories (such as constructivism, distributed learning, and social shared cognition) state that students learn well together.

However, in computer training the results are less consistent. A meta-analysis conducted by Shlechter (1991), revealed no consistent effects for individual small group or learning on student's academic achievement or retention scores. However in a meta-analysis conducted by Lou, Abrami and d'Apollonia (2001), results indicated that on average small group learning had significantly more positive effects on student individual achievement than individual learning. Furthermore they found that the effects of small group learning on student individual achievement were significantly improved when the following took place (1) students had prior work experience; (2) cooperative learning strategies were used; (3) group size was small (i.e. two); (4) tutorial rather than exploratory programs were used; and (5) students were either relatively high or relatively low in ability. While these results relate to computer training in general, to date there remains a lack of empirical research surrounding small group versus individual learning specifically in VR training.

VR Training and Mining.

VR training is considered a cost effective and safe alternative to real world training within a variety of operational environments. Mining is one such environment, where the hazardous and isolated working conditions often limit the type of training that can be carried out. By providing personnel access to virtual environments, high risk situations may be avoided through improved knowledge, skills and decision making within the workplace. In addition, personnel will be able to practice infrequent scenarios, and thus maintaining a suitable and safe level of preparedness (Tropp & Schofield, 2004). For instance, by simulating hazardous working conditions, VR allows the development of skills required to identify potential hazards in the workplace, assessing the likely severity of the hazard and assessing the likely chance of the hazard leading to an incident. Furthermore VR training allows new miners the opportunity to experience virtual environments duplicate to a real world they are yet to experience.

Many mining academics have suggested that VR training allows for a greater understanding of mine environment processes than previous forms of training (i.e. lectures), as personnel are exposed to hazards, procedures and day-to-day operations in a safe, highly visual and interactive manner (Stothard, Mitra & Kovalev, 2008; Tromp & Schofield, 2004). As such a variety of VR simulations have been designed and developed for the purposes of mining training in universities across the world. Under this project, the recent collaboration between University of New South Wales, University of Adelaide, BHP Billiton, RESA, TAFESA and SkillsDMC has developed a VR safety training program for personnel at the South Australian Olympic Dam site. The training program, 'Working at Heights' is designed to familiarise the user with working at heights in different situations across the surface mine. Individual training modules of the program include inspection of an open trench, inspection of good and bad scaffolding, operation of an elevated work platform and changing a light globe.

While many argue within the mining industry (and across the VR community at large) that VR training is the way forward, others state that the in many cases the use of VR training is yet to reach its first step of acceptance and is far from being used as it could be (Schmidt and Robmann, 2004). In addition to cost and the customary resistance to change in the industry, the acceptance of VR remains slow due to the fact that training remains void of providing appropriate instructional methods. Similarly to other industries, there is a need to bridge the gap between the recent advances in training research (i.e. cognitive load) and technology in practice. Thus, the challenge to training developers and simulator designers is to develop systems that use technology to promote learning.

Instructional Design and VR.

The vast majority of the research into virtual environments for instructional use is technology driven with a lack of consideration surrounding the human factor. Yet for VR to be an effective instructional tool, it is not sufficient to focus solely on maximising the fidelity of object renderings and behaviours. According to Salas, Bowers and Rhodenizer (1998), the instructional features embedded in the VR environment determine the success of the training more than the VR environment can on its own. Furthermore, according to Moreno and Mayer (2002) as long as instructional methods promote appropriate cognitive processing, then media does not seem to matter. Instead one must consider how the environment can facilitate effective learning experiences by focusing on a cognitive theory of how people learn from technology (Mayer, 2001; Moreno et al, 2001). According to the cognitive theories of instructional design, efficient learning depends crucially on optimising the load on the learners Working Memory. Where an overload causes confusion, an underload causes boredom and inattentiveness. In addition, as instructional design cannot change the intrinsic cognitive load, one of the most important aspects of the cognitive load theory for VR designers is extraneous cognitive load.

Aims of the controlled study at UNSW

As the instructional design and learning components of VR are often overlooked, the aim of the study is to evaluate the Working at Heights Module developed by the collaborators in this project. Specifically, the study's aims are twofold. Firstly, the UNSW and the collaborators are interested in understanding whether the VR training enables the trainee to experience an increase in human interaction (measured by levels of immersion and presence) as opposed to PowerPoint training. Secondly, they are interested in determining whether the VR module is a more effective training tool compared to the pre-existing PowerPoint training method. The 'effectiveness' model adopted for this evaluation, is Kirkpatrick's (1959) learning evaluation framework. Three of the four levels of evaluation have been adopted, and each successive evaluation level is built on information provided in the lower level. Evaluation at level one measures how participants in a training program react to it. It attempts to answer questions regarding the participants' perceptions (i.e. did they like it? was the material relevant to their work?). Evaluation at level two attempts to assess the amount of learning that has occurred due to a training program. Specifically it assesses the extent students have advanced in skills, knowledge, or attitudes. Retention tests are often used to assess learning at this level. Finally level three of Kirkpatrick's model measures the transfer that has occurred in learners' behaviour due to the training program. Evaluation at this level attempts to examine whether the newly acquired skills, knowledge, or attitudes are being used by the learner back on the job.

Method: Evaluating Virtual Reality Learning in a Mining Context

Participants and Design

The participants were 60 students from the University of New South Wales. Each participant was randomly allocated to one of three instructional conditions (n = 20). The instructional conditions included PowerPoint in a Group Setting (PP), Simulation in a Group Setting (SG) and Simulation in an Individual Setting (SI). All participants were novices to mining safety. The mean age of the entire sample was 19.72 years (SD = 2.16, range = 17 to 26), and 55% of the sample were female. Across the three instructional conditions, no significant differences were found for age or gender. Comparisons were made across the three instructional conditions on measures of knowledge, immersive tendency, presence and satisfaction.

Apparatus.

VR-based system.

The system comprised of a projector, large flat screen, PC, stereo speakers, and a joystick. The virtual image was projected onto a flat 3x3 metre screen, with the actual projected area approximately 2.5x1.6 metres in size. The projector was a Sanyo projector capable of 1280x1024 at 60Hz. The instructional module was presented in a 16:10 widescreen format at a resolution of 1280x800 pixels. The PC was equipped with an Intel Core 2 Duo running at 2.4 GHz, 2GB of RAM, an NVidia GeForce 7900 GT graphics card, and an inbuilt sound card. The stereo sound was delivered through a pair of PC speakers. A 19" LCD monitor was used as a secondary, cloned display. A consumer joystick was used to navigate the virtual world. The joystick's buttons were also used to select and manipulate objects, answer questions, and focus on points of interest in the virtual world.

During the design phase of the VR instruction, key principals of instructional design were adopted in order to influence the participants' ability to learn the appropriate safety processes. These principles included optimising cognitive load and encouraging schema formation.

To reduce extraneous processing and thus cognitive load, three evidence-based instructional principles outlined in Mayer (2008) were adopted. These principles included the *redundancy principal*, which states that people learn best from animation and narration as opposed to animation, narration and on-screen text; *signalling*, whereby learning is enhanced when the learners' attention is guided towards the relevant material by highlighting the essential material in the lesson; and the *temporal contiguity principal*, which states that learning improves when corresponding narration and animation are displayed simultaneously, as opposed to successively. As a result in the VR module, on-screen written text was used sparingly to signal relevant material, and was only displayed after the simultaneous computer-based narration and animation was presented. To foster essential processing, the *segmenting principal* from Mayer (2008) was also followed. This principle states that when narrated animation is presented in learner-paced segments rather than as a continuous presentation, learning is improved. As a result, at the end of each segment of the module a CONTINUE button appeared at the bottom left hand corner of the screen.

During design phase of the VR instruction, schema formation was also considered. Learning is most efficient, effective and satisfying when the participant is able to arrange information from the instructional program instead of learning through rote methods. As a result, a mix of instruction and practice was developed. This mix was achieved by first providing safety information as instruction and, to promote practice, allowing the participants to test their knowledge by asking them to answer a range of multiple-choice questions.

The PowerPoint-based system

This system comprised of Microsoft PowerPoint software in addition to the same projector, large flat screen and PC used in the VR instruction. Instead of using the joystick, the computer mouse was used. Static screen shots from the VR module were presented and narration was given by the experimenter. Figure 34 shows selected frames from the VR module. Printed text was again used to signal relevant material, but, in this case, was presented simultaneously with the images and narration. The safety content provided was identical to the VR instruction. Furthermore, the structure of the PowerPoint instruction was similar the VR instruction, with the first half of the instruction providing information on safety and the latter half testing the participants' knowledge via multiple choice questions.

Materials

The paper-and-pencil material included a demographic information sheet, Immersive Tendency Questionnaire, Presence Questionnaire and a Satisfaction survey.

Demographic information.

Demographic information was gathered relating to the participants age, gender, and mining experience.

Immersive Tendency Questionnaire (ITQ))

The 28-item ITQ was administered to measure the extent of involvement participants experience in relation to visual material (Witmer & Singer, 1998). The measure consists of three factorial subscales, which include a) *involvement* (the tendency to become involved in activities); b) *focus (*the tendency to maintain focus on current activities and games); and c) *games (*the tendency to play video games). The questionnaire is presented in Appendix, along with information on the factor loadings. Items on the ITQ are presented on a seven-point rating scale.

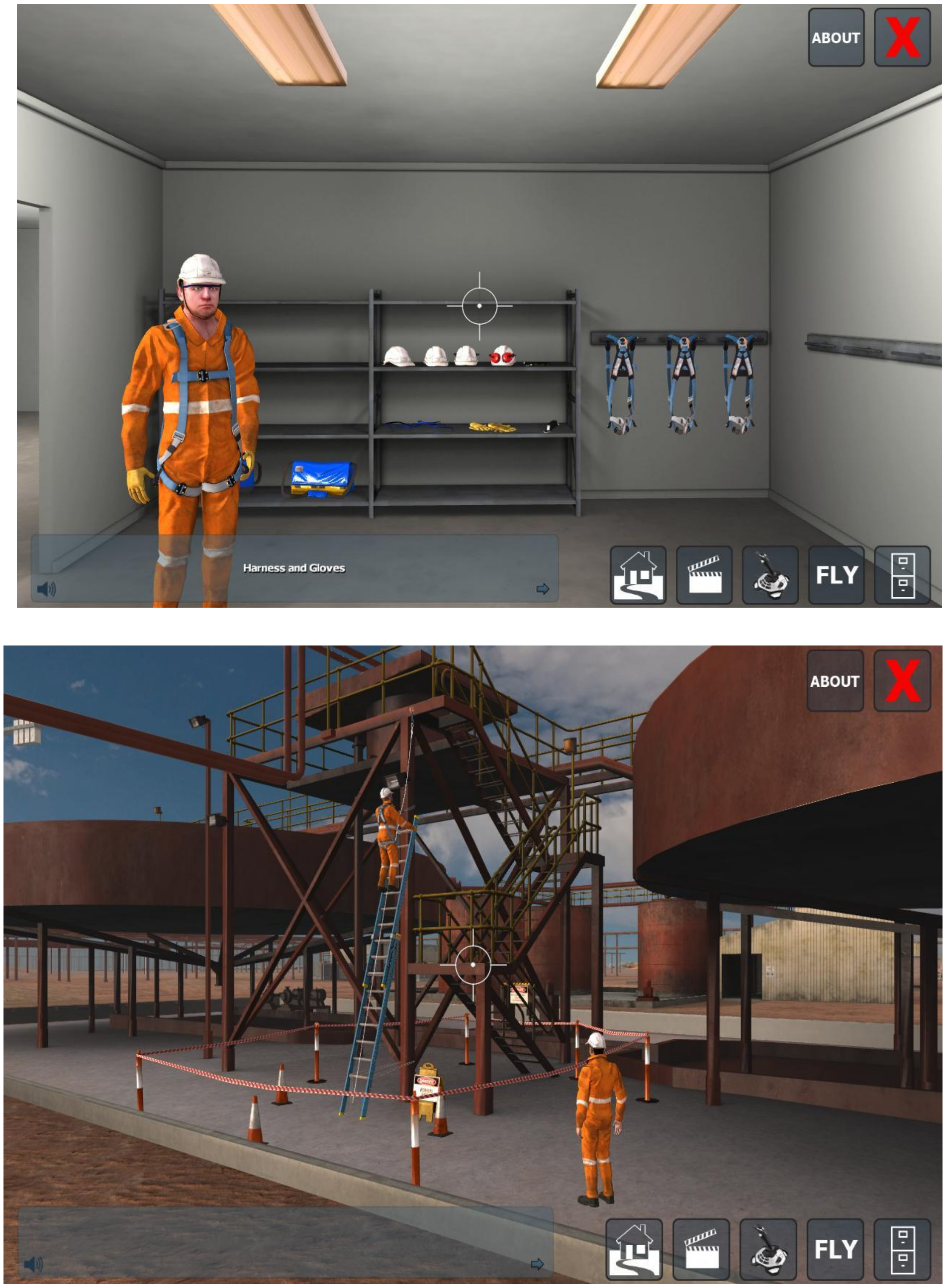

Figure 34. Selected images from the VR system – Working at Heights.

Presence Questionnaire (PQ)

The 32-item PQ was administered to measure factors relating to the participants perception of the instructional system featured. The PQ contains four factorial subscales, which include a) *control* (the extent to which individuals are in command of the instructional environment), b) *sensory* (the extent to visual and auditory information transmitted in the instructional environment), c) *distraction* (the extent to concentration the participant holds towards the instructional environment), and d) *realism* (the degree of authenticity of the VR environment). The PQ and information on the factor loadings are displayed in Appendix. Similarly to the ITQ, items on the PQ are presented on a seven-point rating scale

Satisfaction survey

The 10-item satisfaction survey is presented in Appendix. The questionnaire asked participants to rate on a 7-point rating scale their level of interest, control and perceived difficulty of the material experienced in the instructional environment. This satisfaction survey also serves to evaluate Level 1 of Kirkpatrick's Learning Evaluation Model, namely, reactions.

The computerised materials administered in this experiment consisted of two tests examining the knowledge acquired from the instructional environment.

Knowledge tests.

Participants were given computerised knowledge tests which served as a measure of learning. The first test included 17 multiple-choice questions presented on a small PC computer screen (17 in). The computer graphics varied from the graphics used in the training, as a different location of the mine was used. This test served to evaluate both short-tem recall and transfer of training. Each question included four answer options, which are presented in Appendix. Selections were made by the participant using the computer mouse. The second test was administered to participants one week after the training via email using Microsoft Word. The same 17 questions were asked, however the order of the multiple choice options were altered. This test served to evaluate the retention of learning.

Procedure.

Each participant was randomly assigned to one of the three instructional conditions (PP, SG, SI). Within the two 'Group' conditions, participants were trained in clusters of three to five, and were seated together. In these two conditions, the experimenter was in control of the computerised systems via the mouse or joystick. Within the ‘Individual’ condition, participants were trained independently and as such were in control of the joystick. All participants sat approximately 3 metres from the screen. After providing consent and demographic information, participants were then given an oral brief by the experimenter. The brief explained that the participants would be provided with two paper-and-pencil questionnaires to complete, and would be trained and then tested on “how to safely change a light globe in an open cut mine”. The participants were then instructed to complete the Immersive tendency Questionnaire. Training was then given and was followed by a ten minute break for all participants. The small PC screen ‘recall and transfer’ test was then administered. Finally, the satisfaction survey was given. Exactly one week later, the participants were then administered the final retention test via email. A summary of the conditions used in the experiment is displayed below in Table 21.

Condition	Method		
	Image	Audio	Control
PowerPoint in a Group Setting (PP)	Receive static images and written text simultaneously on large flat screen computer	Receive narration from facilitator simultaneously with images and written text	Facilitator, via mouse
Simulation in a Group Setting (SG)	Receive animation followed by written text on large flat screen computer	Receive narration from VR system simultaneously with animation	Facilitator, via joystick
Simulation in an Individual Setting (SI)	Receive animation followed by written text on large flat screen computer	Receive narration from VR system simultaneously with animation	Participant, via joystick

Table 21. Experiment Design

Results: Evaluating Virtual Reality Learning in a Mining Context

Comparisons were made across the instructional groups on each of the dependent measures: presence, knowledge, and satisfaction. For each measure, a multivariate analysis of variance (MANOVA) was conducted. Two comparisons were conducted, the first examining the difference between the PowerPoint and Simulation in a Group Setting (PP v. SG) conditions and the second examining the difference between Simulation in a Group versus Simulation in Individual setting (SG v. SI). As orthogonal comparisons were not adopted within this experiment, a significance criterion of $p<.025$ was set across the entire analysis.

PowerPoint versus Simulation Training in a Group Setting

Prior to examining the differences between the two instructional groups (PP and SG), scores on the Immersive Tendency Questionnaire (ITQ) were analysed. The means and standards deviations of the questionnaire are presented in Table 22. No significant differences on the ITQ were found between the two groups, $F(1, 38) = 0.74$, $p > .025$, $\eta_p^2 = .02$. This result indicates that the overall tendency of the participants to be involved in visual material was similar across both groups.

	ITQ	
Group	M	SD
PowerPoint	110.80	16.05
Sim Group (SG)	114.90	13.97

Table 22. *Mean scores on ITQ and Corresponding Standard Deviations for PP and SG training.*

Scores from the Presence Questionnaire (PQ) were then analysed. Table 23 presents the means and standard deviations across the two groups in relation to the four subscales in addition to total PQ score. Within the sample of 40 participants, reliability (Chronbach's alpha) of .71 for the PQ was achieved. As expected, significant differences were found between the two instructional groups. In comparison to the PowerPoint group, participants exposed to the VR experienced a significantly larger degree of: *control* in the training environment, $F(1, 38) = 5.56$, $p < .025$, $\eta_p^2 = .13$; *sensory* information transmitted from the environment, $F(1, 38) = 17.56$, $p < .01$, $\eta_p^2 = .32$; and *realism* and authenticity from the training scenes, $F(1, 38) = 6.45$, $p < .025$, $\eta_p^2 = .15$. The overall presence (i.e. Total PQ) experience by participants in the VR group was also significantly greater than the presence experienced by the PowerPoint group, $F(1, 38) = 9.25$, $p < .01$, $\eta_p^2 = .20$. The only PQ subscale that was not significantly different across the two groups was *distraction*, $F(1, 38) = 0.60$, $p > .025$, $\eta_p^2 = .02$. This finding reveals that the willingness of the participants to concentrate on the training and ignore possible distractions was similar across both instructional groups.

	PQ									
	Control (out of 70)		Sensory (out of 77)		Distraction (out of 35)		Realism (out of 49)		Total (out of 224)	
Group	M	SD	M	SD	M	SD	M	SD	M	SD
PP	39.50	9.49	31.15	10.12	25.15	4.61	24.05	6.05	121.15	18.97
SG	46.90	10.33	44.95	10.70	23.90	5.59	28.50	4.98	142.45	24.93

Table 23. Means and Standard Deviations on the Presence Questionnaire for PP and GS Groups.

Knowledge and Retention test scores were then analysed. A significant correlation exists between the two tests, r = .67, p<.01.The means, standard deviations and percentage correct values for both tests are displayed in Table 24. Figure 35 also depicts the percentage correct scores on both tests for both groups. No significant difference was found between the PowerPoint and VR groups on the knowledge test, $F(1, 38) = 0.07$, $p > .025$, $\eta_p^2 = .00$, or the retention test, $F(1, 38) = 0.04$, $p > .025$, $\eta_p^2 = .00$.

Group	Knowledge			Retention		
	M	SD	% C	M	SD	% C
PP	14.60	1.96	85.9%	14.15	1.81	83.2%
SG	14.45	1.64	85.0%	14.05	1.47	82.6%

Table 24. Means, Standard Deviations and Percentage Correct Values on the Knowledge and Retention Tests for the PP and SG Groups.

Figure 35. Percentage Correct Scores on the Knowledge and Retention Tests for the PP and SG Groups.

Across the 9-item satisfaction survey, only one significant difference was found between the two groups. This difference was for the question "Please indicate the perceived level of realism in the visual material". The results for the PowerPoint group were, M = 3.75, SD = 1.48; and for the SG group M = 4.80, SD = 1.19. The individuals in the GS group perceived the realism of the training to be significantly greater than the PP group, $F(1, 38) = 6.08$, $p > .025$, $\eta_p^2 = .14$. This item on the satisfaction survey also significantly correlated with the PQ (i.e. PQ Total), $r = .65$, $p < .01$. However, the Realism item did not correlate significantly with the PQ Realism subscale.

Group Simulation Training versus Individual Simulation Training:

Presented in Table 25 are the mean and standard deviation scores on the ITQ for both VR groups. Once again no significant group differences on immersive tendency were found between the groups, $F(1, 38) = 1.31$, $p > .025$, $\eta_p^2 = .03$.

	ITQ	
Group	M	SD
Sim Group (SG)	114.90	13.97
Sim Individual (SI)	120.00	14.19

Table 25. Mean and Standard Deviation for ITQ for SG and SI groups.

The means and standard deviations from the Presence Questionnaire for both VR groups are displayed in Table 26. In relation to this sample (n = 40), reliability (Chronbach's alpha) of .80 for the PQ was achieved. Across the four PQ subscales no meaningful variations were found between the two VR groups. For instance, no significant difference appeared on *Control*, $F(1, 38) = 0.11$, $p > .025$, $\eta_p^2 = .00$; *Sensory* information, $F(1, 38) = 0.75$, $p > .025$, $\eta_p^2 = .02$; *Distraction*, $F(1, 38) = 0.03$, $p > .025$, $\eta_p^2 = .00$; or ***Realism***, $F(1, 57) = 0.05$, $p > .025$, $\eta_p^2 = .00$. Furthermore, no significant difference appeared across the two groups on the overall Presence Questionnaire (i.e. PQ Total), $F(1, 38) = 0.46$, $p > .025$, $\eta_p^2 = .01$.

	PQ									
	Control (out of 70)		Sensory (out of 77)		Distraction (out of 35)		Realism (out of 49)		Total (out of 224)	
Group	M	SD	M	SD	M	SD	M	SD	M	SD
SG	46.90	10.33	44.95	10.70	23.90	5.59	28.50	4.98	142.45	24.93
SI	47.80	6.80	47.70	9.31	24.15	2.25	28.9	5.82	147.10	17.91

Table 26 Means and Standard Deviations on the Presence Questionnaire for SG and GI Groups.

Table 27 presents the means, standard deviations and percent correct scores on both knowledge tests. Figure 36 also lists the percentage correct scores on both tests for both VR groups. A significant correlation exists between the two tests, r = .68, p<.01. In relation to the Individual VR group, a significantly higher score was achieved for both the knowledge test, $F(1, 38) = 6.58$, $p < .025$, $\eta_p^2 = .15$, and retention test, $F(1, 38) = 5.48$, $p < .025$, $\eta_p^2 = .12$. Furthermore, a significant retention loss was found for both VR groups, $F(1, 38) = 5.94$, $p < .025$, $\eta_p^2 = .14$. However, the retention loss was not significantly different between the two groups, $F(1, 38) = 0.07$, $p > .025$, $\eta_p^2 = .00$.

Group	Knowledge			Retention		
	M	SD	% C	M	SD	% C
SG	14.45	1.64	85.0%	14.05	1.47	82.6%
SI	15.55	0.99	91.5%	15.05	1.28	88.5%

Table 27. Means, Standard Deviations and Percentage Correct Values on the Knowledge and Retention Tests for the SG and SI Groups.

Between the two simulation groups, across the 9-item satisfaction survey no significant differences were found.

Finally, in order to examine whether a relationship existed between the Presence Questionnaire and the two knowledge tests, bivariate correlation analyses were conducted with all 60 cases. As presented in Table 28 below, overall PQ (as depicted by Total PQ) failed to correlate significantly with either of the knowledge tests. The only significant correlations occurred between the Distraction subscale and the two knowledge tests. This finding suggests that the more the observer can ignore possible distractions around them, the higher the knowledge and retention. Upon closer inspection, it was evident that the only significant correlations were between the knowledge test and the distraction subscale in the Simulation Group (SG) condition, r =.551, $p < .05$. While the sample is considerably small for such an analysis (n = 20), this result suggests that this group were able to concentrate on the virtual environment, and as a result this led to an improvement in their knowledge. However, as displayed above, this group on average obtained the lower knowledge scores, suggesting factors other than distraction influenced possibility of learning.

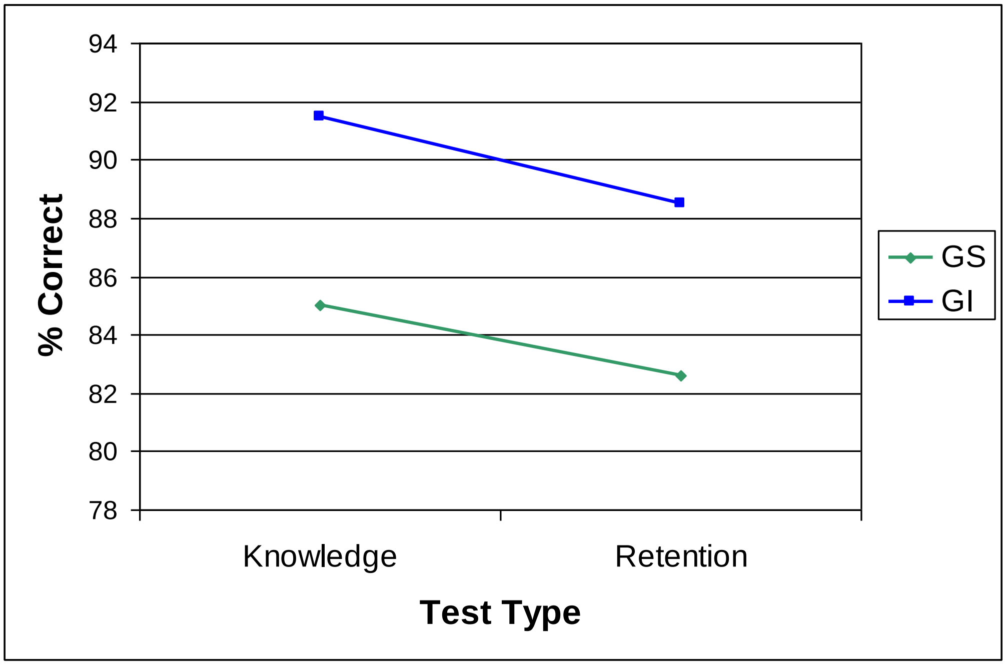

Figure 36. Percentage Correct Scores on the Knowledge and Retention Tests for the PP and SG Groups

Test Type	PQ				
	Control	Sensory	Distraction	Realism	Total
Knowledge	.00	-.09	.31*	.04	.02
Retention	.08	-.06	.26*	.12	.07

* denotes $p<.05$; **denotes $p<.01$.

Table 28. Correlation analyses across the PQ and Knowledge Test for the Entire Sample of participants (n=60).

Discussion and Conclusions: Evaluating Virtual Reality Learning in a Mining Context

Research into VRE remains fragmented and unsystematic. This is due in part to the fact that researchers involved come from many different academic fields (including communication, psychology, cognitive science, computer science, engineering, philosophy, and the arts). In recent years, an important expansion of work has centred around the educational value of VREs. This field of work on VR learning remains in its formative years and as such many have called upon an extension to the research (McLellan, 1996; Dede, Salzman, Loftin & Ash, 2000; Moreno & Mayer, 2002). The current study endeavours to add to this growing body of research, by answering the following questions below.

Do more immersive learning environments promote a stronger sense of presence than no immersive learning environments?

The current study hypothesized that more immersive learning environments lead to a greater sense of presence. By comparing the PQ scores across the PP and VRG conditions, a significant difference was found. The overall presence experienced by students was significantly greater in the immersive training group, with a stronger sensation of "being there" experienced when the training was delivered as a VR desktop display, rather than a PowerPoint presentation. Therefore, the current experiment yields evidence that media has an effect on student's sense of presence. However, it is important to note that while overall PQ was greater in the VRG condition, when examining the PQ subscales, feelings of distraction were similar across both groups. This result indicates that both groups were equally willing to concentrate on the training at hand.

Do more immersive learning environments endorse more (or less) learning than no immersive learning environments?

As highlighted above, there are conflicting arguments within the literature, with regards to the impact immersion has on learning. One group argue that learning in immersive environments is promoted through an increase in presence and interest, and a decrease in cognitive load (i.e. Renninger, Hidi & Krapp, 1992; Jonassen, Peck & Wilson, 1999; Smith & Woody, 2000; Chen, 2006). Whereas others argue that immersion inhibits learning as individuals become distracted and overloaded (i.e. Norman, 1993; Moreno & Mayer, 2000; Mayer et al, 2008). Within the current experiment, a comparison was made in regards to learning (recall, quasi transfer and retention) between the PP and VRG conditions. Similarly to Mayer and Moreno (2002), while the group presented with an immersive learning environment (VRG) experienced a higher sense of presence, this did not lead to a significant difference in learning in comparison to those presented with a no immersion (PP). While both groups experienced a slight retention loss, no significant difference was found between the two groups on the knowledge tests. An increased sense of presence did not lead to an increase or decrease in learning. In addition, in relation to interest theory, as measured by the satisfaction survey, there was no significant difference between the levels of interest the two groups experienced. Therefore, the findings in the current experiment are not consistent with the view that immersion promotes learning, nor that immersion impedes learning.

Does active learning in VREs endorse more (or less) learning than passive learning in VREs?

Within the literature there exists a debate over whether active learning (whereby the user has control of the VRE) leads to an increase (i.e. Christou & Bulthoff, 1999; James, Humphery & Vilis, 2002) or decrease (i.e. Phelps, Fritchle & Hoffman, 2004; Chen, Toh & Ismail, 2005) in learning. Within this study, a comparison was made in regards to learning (recall, quasi transfer and retention) between the passive (VRG) and active (VRI) instructions. While presence experienced was similar across both groups, a significant difference was found across learning for the two conditions. By involving students in the learning task, the active group (i.e. VRI) experienced significantly greater scores on both knowledge tests. This finding is consistent with the view that active learning in VREs promotes more learning. Furthermore, a certain level of guidance was provided for those actively controlling the VR system (namely directional arrows), it is suggested that the active learners experience an appropriate level of cognitive load. In addition, due to their lack of involvement, it may be the case that the passive group were in fact underloaded, thus creating boredom, inattentiveness, and a reduction in learning. Overall, this is a promising finding for VR training, as the advantages of individual learning have the potential to transcend into distance or mobile learning (Inoue, 2007). Within the mining sphere for instance, due to the isolated nature of many sites, the opportunity to train new employees on safety processes before they arrive at the site (i.e. on the home PC) is not only appealing logistically, but also has the potential to save time and money.

Limitations and Future Directions

The conclusions drawn in this study are influenced by both the participant's familiarity with the technology and also the topic at hand. Participants in this study were novices to mining safety and according to Hoffman, Prothero, Wells and Groen (1998), this lack of meaning may negatively influence the level of presence the individual's experience. Furthermore, fully immersive VR technologies were not adopted in this study. While objects in the desktop display VR were three dimensional, reality could still disappear with the wave of a hand. Thus in certain cases, the immersive effect of virtual reality may have become jeopardised (Allison, 2008).

Conclusions drawn regarding the retention loss from the two knowledge tests should also be considered. Within this study, the retention loss findings were somewhat confounded by the test medium. While the questions presented in both tests were identical, Test 1 was presented using VR technology, and Test 2 using Microsoft Word. Furthermore, while Test 1 was presented to all participants using the same computers, Test 2 was displayed on participants' home computers, resulting in a lack of a common platform (such as different sized screens).

Finally the role of social context should be considered. Several theories state that students working in small groups produce higher achievement than students working alone (Yager, Johnson & Johnson, 1985; Rose, 1995). Yet within this study, overall those training individually yielded higher knowledge scores. To date within VR research there remains a lack of empirical evidence surrounding the influence of social context. As discussed below, it is therefore suggested that future research explores the role of social context in VREs.

In relation to future directions, additional research is required in order to explore the circumstances is which VRE can promote learning. For instance, would there be a variation in the findings if the training was longer (i.e. more than one module)? In addition, would the results vary if mining experts were tested rather than novices to mining safety? As mentioned above, social context may also influence the results. Thus it is also suggested that future directions consider the inclusion of a comparison group, namely PP in individual setting. In doing so, the influence of social context (i.e. group versus individual) on learning in both PP and VR can be established. It is also suggested that future research examines the influence of screen size (i.e. large versus small) to determine whether this affects presence and/or learning. Furthermore, as mentioned above, fully immersive VREs were not included in this study. As such, future research should also include the examination of mining safety training through 360 degree screens.

In relation to cognitive load, it may also be the case that the content of the safety training is not taxing enough, thus creating a cognitive underload. While ceiling effects were found in this study it would be unethical to make the training more complex, as it relates to occupational health and safety. However, future research could involve other forms of skills training. In addition, similarly to Homer, Plass and Blake (2008) future research could also include measures of cognitive load, to determine in what VR training settings cognitive underload and overload takes place.

Another interesting area of research involves influence of different learning styles in VREs. The beauty of VR formats are that they can be used to present information in several modalities, thus addressing different learning styles. For instance, Homer, Plass and Blake (2008) found learner's preference and variations in the multimedia learning environment interact to affect cognitive load. In addition, Smith and Woody (2000) found that individual differences moderate the impact of multimedia approaches on student learning. Thus in relation to future directions, an examination of the learning styles most common to mining personnel could be established.

Summary

In summary, while the BHP Billiton 'light globe' VR training module facilitated an increase in presence, in comparison to the PowerPoint instruction it did not promote an increase in learning (recall, quasi-transfer and retention). Furthermore, trainees experiencing the VRE did not experience a significantly greater level of enjoyment (as measure by the entertainment item in the satisfaction survey). As a result, in relation to Kirkpatrick's framework, the VRE was not more 'effective' than the PowerPoint instruction. However, promising findings did eventuate when the trainee was given control over the VRE. Overall, the findings from this study reveal that VR technology does not always promote an increase in learning. Thus to ensure that VR is an effective instructional tool, immersion, fidelity and human learning have to be taken into consideration. This will be achieved through the cooperation of instructional and technological experts during the design and development of virtual reality tools.

Deployment at Olympic Dam Site and Comparison to Thebarton and UNSW Delivery.

Objectives

One of the project aims was to deploy the Pilot Module ‘Working at Heights’ produced under the project at the Olympic Dam Expansion (ODX) Project. Unfortunately, an unforeseen downturn in the global economy caused the project team on the BHPB Billiton ODX side to be retrenched causing some limitations in the potential deployment on site. Also, it can be seen from the Thebarton and UNSW evaluations, that it is not feasible to perform a scientific study on site at this stage. A basic satisfaction study was all that could be achieved within the scope of the project.

The Olympic Dam site kindly accommodated a small deployment on site and while the data collection was restricted due to site logistical issues, sand-storms and the like, a general satisfaction survey was conducted and a general overview obtained from personnel exposed to the simulation. In an attempt to expose the ladders module to as wide variety of people as possible, the module was deployed at Olympic Dam, and again temporarily at UNSW – (to graduate mining engineers on individual personal computers). The aim was a comparison of individual and group simulation satisfaction.

Deployment

The deployment at Olympic Dam was performed at the ‘Pilot Plant’ training site. The classroom is shown in Figure 37. The deployment to UNSW Graduate Students is shown in Figure 38.

At Olympic Dam, the SRTA trainer exposed the various mine workers to the simulation over a period of four weeks and was asked to collect Satisfaction/Rating data only. Their assistance with this data collection was greatly appreciated – given the remoteness of the site. The aim was to use the same lesson plan as used in Thebarton and simply establish how the trainees felt about the simulation. The simulation referred to in the survey is the ‘Change a light Globe simulation: Using Ladders’ developed by UNSW Mining and Psychology following the Thebarton experimental deployment.

The deployment at UNSW to a group of UNSW Mining Engineers was performed under the Technology Management in Mining Course. A 1 hour lecture on simulation was given and then the Changing a light globe module was administered to individuals on a PC.

The satisfaction and rating survey used in the data collection is presented in Appendix.

The Mining Engineers in the deployment at UNSW were from many different countries.

Figure 37. Simulation Training Session at Olympic Dam.

Figure 38. Simulation training Session at UNSW – Individual Personal Computers.

Results

The results from the Olympic Dam Deployment and the UNSW Deployment are shown in Figure 39 and 40. Thirty-two miners were surveyed at Olympic Dam. Demographic data was not collected at Olympic Dam in this instance due to time restraints.

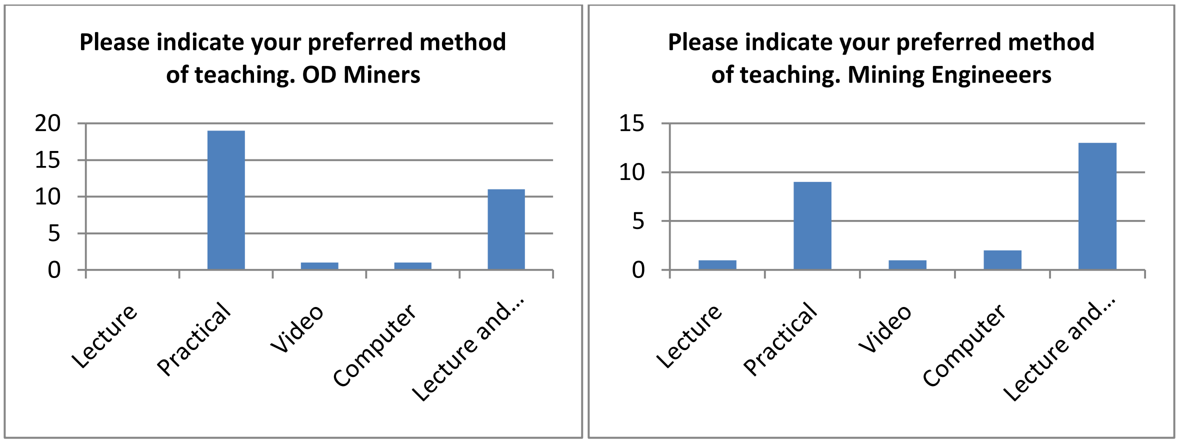

Figure 39. Preferred method of teaching.

The indication from the miners reviewed on site at OD was that they like practical based training the most. They also like lecture and computer based training – which includes the simulation. Very few like pure computer based training and video. None of the miners liked lectures. This is not unexpected as these people are practical, site based people.

The technology management course at UNSW also preferred practical training and surprisingly don't like lectures or computer training. They do like lectures and computer based learning. Again, these are mostly practical people.

Figures 40 and 41, show the comparison of satisfaction for the OD miners compared to the UNSW mining engineers. The main difference between the two groups being, individual interaction with the simulation at UNSW versus group interaction and instructor lead simulation used at Olympic Dam. Figures 40 and 41 show, the UNSW and the Olympic Dam groups found that the training was engaging. However, in the OD group there were a couple of people who did not. Many of the UNSW group found the training entertaining. A couple of the Olympic Dam people did not.

The UNSW group mostly found the training interactive as did the Olympic Dam group. Two people at Olympic Dam did not.

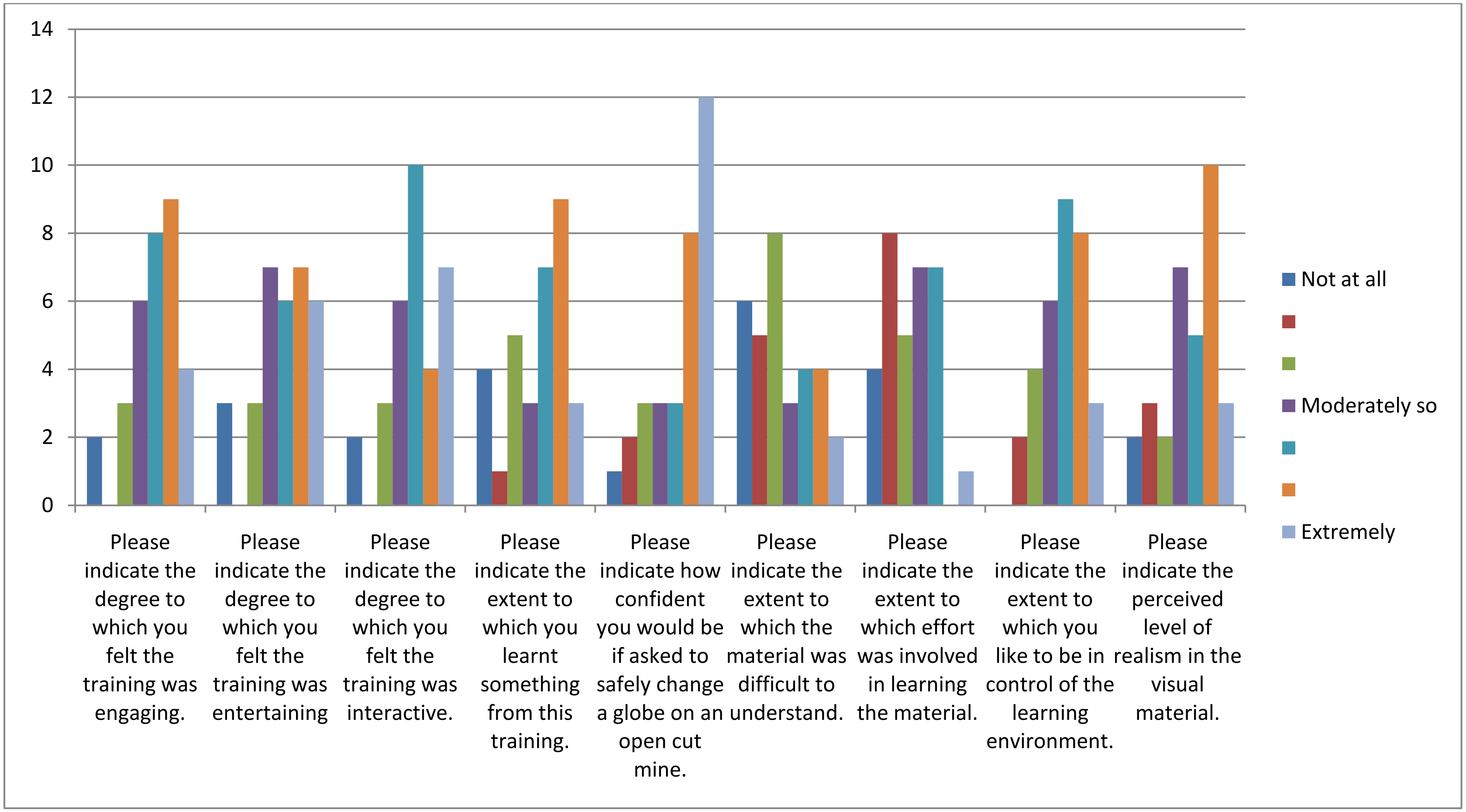

Figure 40. Olympic Dam Working at heights Course. Satisfaction/ Rating Data.

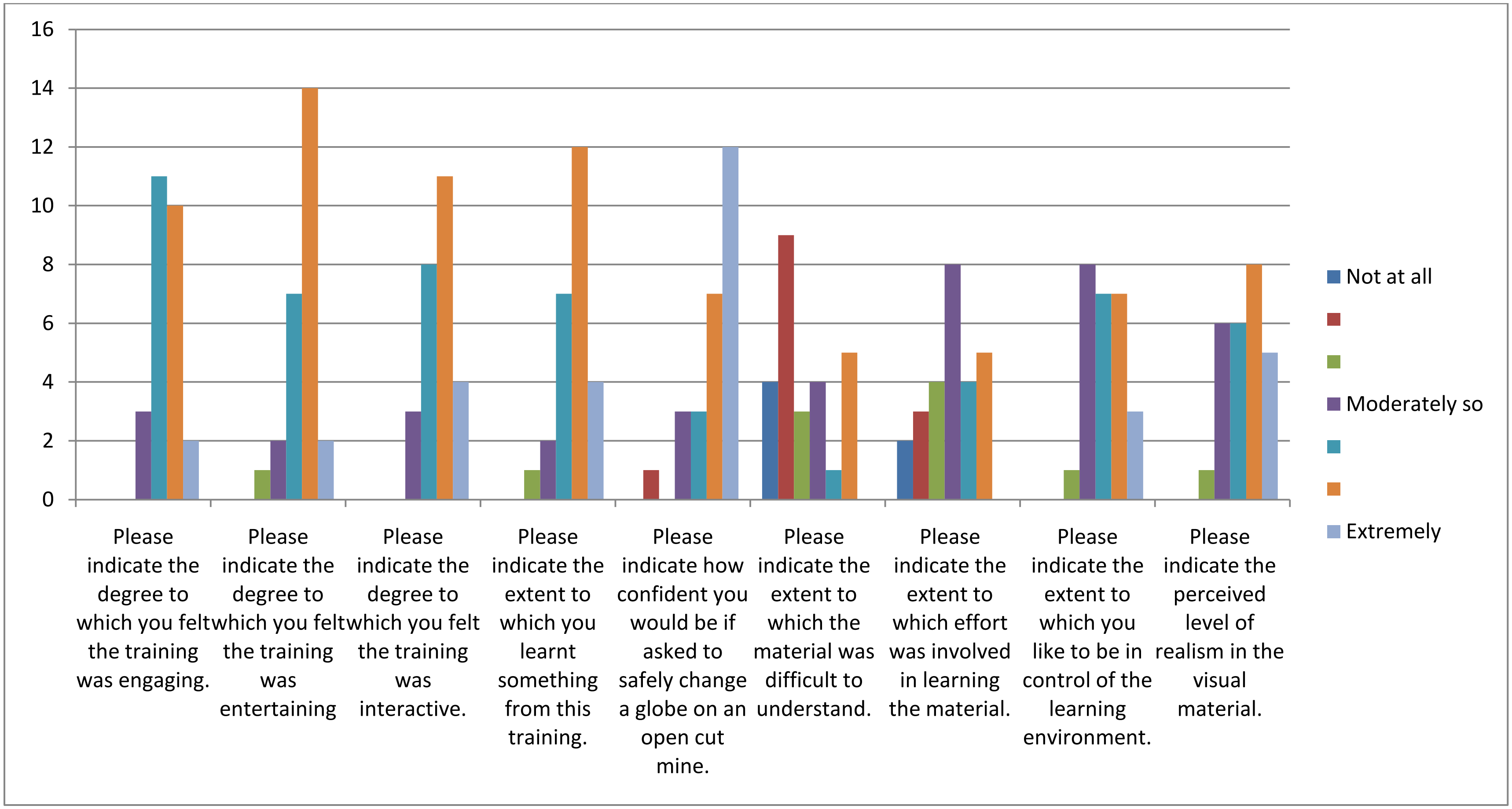

Figure 41. UNSW Technology Course. Satisfaction/ Rating Data.

The majority of people at UNSW found that they learned something from the training. The majority at Olympic Dam also found they learned something from the training. There were also people who did report that they did not learn anything at all.

The majority of people at UNSW and Olympic Dam were confident that they could change a light globe at height on an open cut mine using ladders after the training.

At UNSW some people found the material difficult to understand. This appeared to be less of an issue at Olympic Dam and may be due terminology and language.

At UNSW the effort required to learn the material distributed over the population with moderate effort required. At Olympic Dam the skew is towards little effort involved.

At UNSW the extent to which the trainees like to be in control of the learning environment skews towards extreme, they want to be in control. The same applies at Olympic Dam.

At UNSW the perceived level of realism was high. The same applied to Olympic dam.

Discussion

The deployment at Olympic Dam suffered from unforeseen impacts out of control of the project committee. Despite this, an installation of the pilot project was implemented in a limited form at the Pilot Plant at Olympic Dam and the module is in use. The pilot module can potentially be used for training as part of a training course.

Trainees working at Olympic dam were exposed to the ladders scenario and the data collected shows that this group prefer practical training and then lecture and computer based training. The differences between the populations were that Olympic Dam and UNSW received training via group and individual simulations respectively. The key difference was that the UNSW population found that the training was interactive where the Olympic Dam population found it less so. This may simply reflect the group versus individual training where trainees were left to work through the simulation at UNSW and were guided by the trainer at Olympic Dam. The training was generally found to be engaging, but from the data, there were people at Olympic Dam who did not like the training. This could be for various reasons. The trainees were confident that they could perform the light globe operation following the training in both populations and they both generally thought they learned something. The material was easier for the Olympic Dam population to learn and this may be due to their previous experience or that the level of the simulation was too low. In both populations, the trainees want control of their training. This suggests that the application of simulation to mine workers should be done in a fashion where relevant practical aspects of their daily work and training requirements should be replicated so that they utilise and apply that practical experience within the simulation. That is, the simulation should get them to problem solve within the environment and get the trainees interacting with the environment in much more detail. In some instances and where appropriate they should be able to build their own training materials within the simulation that will equip them with the necessary skills to perform their tasks safely on a real site.

In conclusion, the pilot module was deployed to site and is available for training if required by the Olympic Dam site. Data was collected and has been discussed. There appears to be little difference between group and individual simulation in this case. However, the application of simulation on mine sites requires much more work. A formal on-site implementation of simulation technology in purpose built facilities should also be considered in any future deployment. It has been found by Zhang, Kehoe and Stothard (2009 In Press) that the use of completely immersive environments show a significant difference with respect to training outcomes when compared to the flat-screen implementations presented in this report.

10. Project Discussion, Conclusions and Recommendations

This project reports on the "Feasibility Study Development and Demonstration of Virtual Reality Simulation Training for the BHPB Olympic Dam Site Inductions". The project has demonstrated a capability for the research, development and deployment of a simulation module that addresses issues related to Working at Heights on surface mine sites. The module can potentially be customised and utilised in other industries.

The pilot project aimed to address issues that exist in building and transferring a virtual reality simulation to the hard rock industry. Many simulations have been developed for the coal-industry and it was proposed that a pilot project looking at the issues associated with transferring simulation to the hard rock industry would be an appropriate first step. The two industries are subtly different.

The project has developed a module that is based around Working at Heights, a high risk activity that requires the knowledge and application of a detailed system of and rules and regulations. Working at heights is a very high priority risk area on mine and construction sites.

Comprehensive training courses have been developed to train people in Working at Heights. Much of the information and detail within them is complex. The simulation developed under this project, provides a mechanism for trainers to discuss options within the classroom via an interactive virtual model of the mine-site. The simulation also offers the opportunity for trainees to be exposed to consistent training materials and delivery.

The project has performed a literature search that looked at the development and use of virtual reality simulation in mining and other industries. The literature survey reveals that virtual reality simulation has been in existence for many years and has been adopted by several industries. Some industries such as medical and military have developed sophisticated simulations. Mining has been slow to adopt the technology and there are example simulations dating from the mid-nineties.

In mining and other industries, in the early 2000s, great deal of attention has been paid to developing technology and techniques. Unfortunately, in many instances attention to the development of course material that operates within the simulations has taken second place. This situation has changed in recent years with several research institutions developing meaningful interaction with simulated environments. The need for the inclusion of educational theory relating to cognitive load and instructional design in simulations is discussed in detail in the report.

One of the main issues that must be considered is the human interaction with the virtual environment and also the psychological aspects of using virtual reality simulation. The aim has been to produce high-resolution simulations that aim to provide a sense of presence within the simulation the objective being to give a real experience of being on site. A review of the instructional design also required consideration and is discussed later.

Display technology is not covered in this report. However, the comparison between flat-screen non-immersive simulation and fully immersive simulation using large screens must be considered in any next stage. A parallel study to this project yields encouraging results.

A comprehensive review of games engine technology shows that games engines are the fundamental component of interactive simulation and there are literally hundreds of game engines to choose from. Under the pilot project Virtools software was used on the basis that existing UNSW capability could be quickly leveraged and also the software was customisable to accommodate different display software. The review suggests that in future projects, the licensing issues relating to Virtools may become a barrier and a different game engine may be more appropriate. One of the key issues is the delivery format for the module and any subsequent installation of VR display facilities. The recommendation is that the OGRE game engine be used in preference to Virtools if the simulations do not need to be deployed on large screen cluster based PC systems.

The project was set up as a collaborative project and this in itself has proved to be a complex process to manage. There were six collaborators in the group, two research organisation who were the chief investigators and four collaborators. The contractual side of the project proved complex and for the scale of the project in real dollar terms was out of proportion. Nevertheless, all the collaborators were amenable and reached agreement. The project timeframe was also an issue at approximately twelve months. Momentum had to kept within the project and the necessary communications with respect to acquiring specification and details of equipment to be modelled, lesson plans, learning outcomes and so-on were difficult to maintain. An extra problem was encountered when the BHPB Olympic Dam expansion project team who were key collaborators were unfortunately re-trenched in mid project due to the global financial crisis. This was a serious blow to the project and could not have been foreseen, it was also disappointing that the collaborators were unable to provide extra funds to retain the key BHPB personnel on the project to see it through to completion. UNSW subsequently retained two of the key personnel which affected internal budgets.

The Working at Heights module was built as planned and resulted in five sub modules with a series of different interaction programmed within the environment that looked at the various aspects of working at heights. The documentation used for the pilot module was from various sources among the collaborators. However, the BHPB site documentation proved to be the basis and main focus. Five sub-modules were the result and the input of the industry personnel was excellent.

The Working at Heights module evolved through discussion with people experienced in training for working at heights. The module design was primarily focussed on becoming an integrated part of a working at heights training course and to evaluate the module prior to it being deployed on site, a test deployment was made in Adelaide. The pilot deployment provided some good feedback on how the module would fit in a training program in any subsequent deployment on site. The data collected in Adelaide also revealed that the instructional design and educational evaluation of the module needed closer attention and one of the sub-modules (Ladders) was enhanced.

The educational psychological evaluation of the module resulting from the experimental deployment at Adelaide showed that the instructional design within the module need consideration and a series of experiments comparing a section of the module to traditional PowerPoint methods of training was performed. The design of the module was altered slight to incorporate a more refined instructional design that consisted of a training component and an assessment component. The structure for this modified module was based on modern educational psychology techniques and the evaluation was performed under scientific conditions and produced some interesting results. They key outcomes of the experiment showed that user's of the simulation experienced a sense of Presence in the simulation, giving the trainees and 'experience' of being on site is one of the broader objectives of simulation training. A more concerning outcome in this instance was that the VR training module (ladders scenario) when tested under scientific conditions did not promote an increase in learning. In relation to the Kirkpatrick's framework, the virtual environment in this was not more effective than the PowerPoint instruction under group instruction conditions. However, that said, the images and material in the two modes of delivery were very similar and actually screenshots of the simulation model itself. What is encouraging is that when trainees were given control of the virtual environment themselves, there was an improvement in their scores. This is consistent with the theory that active learners experience an appropriate level of cognitive load. For virtual environment training, the trainee must be able to control their own learning and they must be able to control the environment themselves and be able to interact with it. A parallel study (Zhang, Kehoe and Stothard 2009 – In press) showed significant differences to the working at heights module evaluation.

The module the module was also deployed at the BHPB Olympic Dam Site and as part of the Technology management course at UNSW. The findings show that trainees like to be involved in practical aspects and hence it is logical that the future development of virtual reality training environments for the BHPB Olympic Dam Operations and for other industries that the collaborators see as potential users of simulation technology for training must be centred around the trainees being provided an opportunity to control the environment themselves and also they must interact and problem solve within that environment. Passive, group-based learning environments that attempt to incorporate simulation into a training course may not have the outcomes expected of them. They will only really be a form of video representation and visualisation and for the trainees to acquire the appropriate learning outcomes the instructional design of these courses needs to be assessed. However, they're use is still preferable to pure PowerPoint presentation.

During the project, it also became apparent that the acquisition and consistent access to data and personnel must be considered in future projects through a formal risk assessment of the impact of external factors on the project. The installation of the simulation on site in any future project also must be considered. One of the major issues is budgets, risk and logistics. The project was fortunate in that BHPB OD allowed the module to be installed on site and provided assistance. This assistance was outside of their normal activities and budgeting and for future operations there should be a dedicated point of liaison on site that can co-ordinate installation and training using the simulation. Reliance should not be placed on the busy personnel already at site. A dedicated training person and site contact who becomes the driver for implementation and improvement of virtual reality simulation on site is important. Without ownership, the technology implementation cannot progress from pilot to fully fledged implementation. Project risk should also be evaluated – this project was unfortunate to loose key project members and the main organisation. However, perseverance and dedication of the collaborators brought the project to a successful conclusion.

The conclusions that can be drawn from the project are that collaborative projects are a very good idea in principle and provide access to a 'fledging' technology with very low risk. From a legal context, the number of collaborators may be too high on this particular project though due to its scale. Although having many inputs has been beneficial.

Overall, a quality module has been built and the collaborators have gained experience of these types of project. The project has also shown that the tendency is to want to replicate existing training materials in the virtual mine environment and use the simulation as a visual aid. The educational research has shown that the instructional design and active engagement via interaction is essential in the simulation. Passive lectures are not liked by the trainees. They are practical people and want to do tings themselves as opposed to sitting back and listening.

The recommendation is that work on the Working at Height module should continue and it should be formally implemented on site in a purpose built facility and preferably using large screen implementation on site with a legacy PC or 'Game-Boy' based system for offsite use.

Regardless of the display platform, the module must be developed further and used in a manner that is interactive for all trainees. This may be via problem solving as a group or as individuals. The simulation experience must be facilitated by the trainers and backed up by practical experience of the subject matter where possible.

The module should be customised further to suit the needs of the trainers. Educational and Occupational Psychologists must also be included in the module interaction design and in development of the learning outcomes – cognitive theory must be considered in course design.

Module model development and programming should be performed by a commercial entity to a formal collaborative specification prior to any modelling or programming being performed.

Research and development relating to course design and cognitive theory should continue within the University system and be transferred to industry through a project structure similar to this project.

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Note: The Working at Heights Module and Appendices are located in electronic format on the attached DVD ROM.

12. Appendix

The following can be found in the folders on the DVD.

- Working at Heights Module
- Module Description
- Game Engine Review Comparison Chart
- Thebarton Lesson Plan
- Thebarton Data
- Knowledge Test
- Training Feedback Questionnaire.
- Trainee Comments
- Trainers Comments
- Immersive Tendency Questionnaire
- Presence Questionnaire
- Satisfaction Survey.