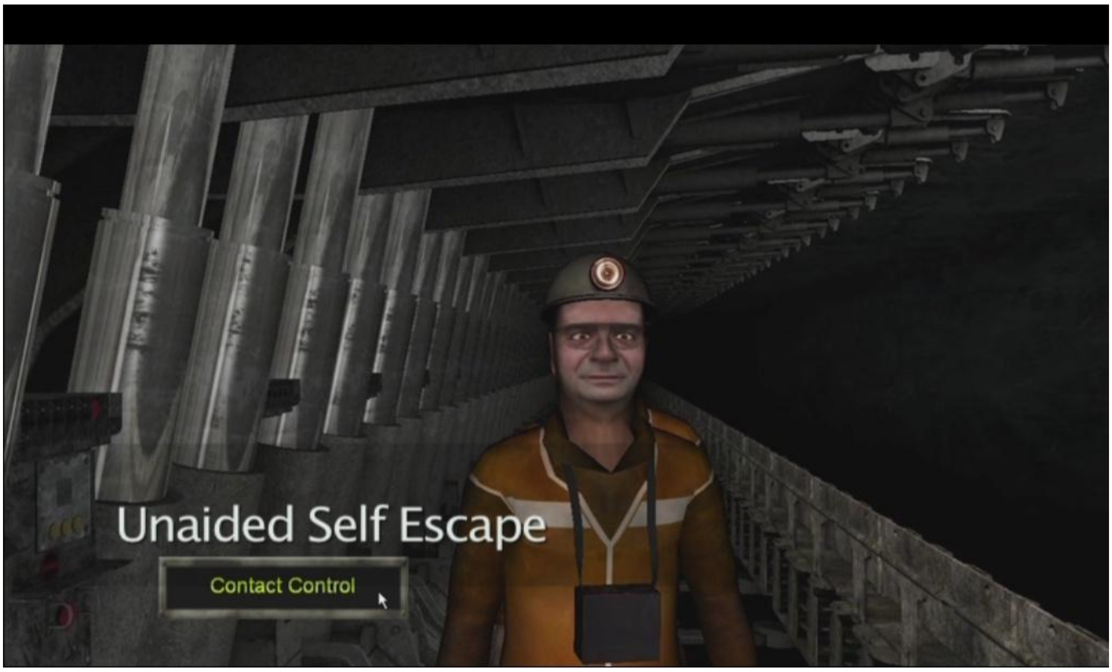
Developing an Enhanced VR Simulation Capability for the Coal Mining Industry



Final Report to:

Coal Services Pty Ltd, Coal Services Health and Safety Trust

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Acknowledgements

Coal Services Pty Limited (CSPL) has supported the development of VR simulation for the mining industry since 2000. CSPL was formed on 1 January 2002 and merged the activities of the former Joint Coal Board and the Mines Rescue Board into one company with responsibility for providing workers' compensation, occupational health and rehabilitation and mines rescue services to the New South Wales coal industry. The main objectives of Coal Services Pty Limited are to,

- Operate an innovative, efficient, effective, competitive and fully funded workers' compensation insurance scheme for the coal mining industry in New South Wales.
- Provide the NSW coal mining industry with an occupational health service that delivers quality medical assessments, rehabilitation, risk and injury management, work environment monitoring and health educational material tailored to the needs of those working in the NSW coal industry.
- Provide a rescue service to the NSW coal industry that can quickly and effectively respond and assist in the control of emergencies at mines enabling the escape/rescue of persons from those emergencies, and to ensure that members of the Brigade are adequately trained in mines rescue procedures.

CSPL is jointly owned by the NSW Minerals Council (through a subsidiary company) and the CFMEU in equal shares and has two wholly owned subsidiary companies – Coal Mines Insurance Pty Ltd and Mines Rescue Pty Ltd.

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Summary

This report describes the processes and outcomes for the UNSW/Coal Services Project "Developing and Enhanced VR Simulation Capability for the Coal Mining Industry".

The report covers

- The installation of a 160 spherical curved screen facility installed at the Argenton Mines Rescue Station.
- The development of a core team of programmers to build the modules effectively.
- The development process for the modules that were built to run on the system and subsequent visualisation systems purchased by Coal Services and Mines Rescue.
- Descriptions of the developed modules.
- The interaction devices and methods developed over the project
- The educational evaluation of the modules and their refinement by the industry experts and trainers
- The presentation of a business plan and model covering the key requirements to place the project on a commercial basis.
- Publications written and presented during the project that allowed the project to be bench marked and set the foundations for continued work.

Contents

Introduction

The CSPL Project "Developing an Enhanced Virtual Reality Simulation Capability for the Coal Mining Industry" was proposed in 2005 as a three-year project concerned with the continued development and implementation of an enhanced capability in virtual reality (VR) simulation for improving OH&S management and performance in the Australian Coal Mining Sector. CSPL had developed and implemented proof of concept simulations prior to commencement of the project based on 'off the shelf' PC technology as identified by Stothard et al (2001).

Under the earlier projects, a core capability in VR simulation had been established and was clearly demonstrated. This capability provided a foundation for developing and expanding the project to a more advanced suite of simulations. However, the technology from the previous project required updating to take advantage of the rapidly changing simulation technology and to make the simulations more realistic and meaningful.

From the outset of this project, the aim was to enhance at least two of the existing simulations and develop several new simulations in line with the findings and recommendations of Stothard and Galvin (2005) where the researchers concluded that simulation technology had advanced significantly since the original Scoping Study of Stothard et al (2001) and that high powered, cost effective technology, was available to simulate complex mining simulations associated with coal mining.

The enhanced VR project proposed that two of the original modules – Rib and Roof Stability and Unaided Self Escape should be enhanced because they offered important OH&S benefits and because they offered a platform on which to base new simulations. It was envisaged that 80% of the equipment and models already built and deployed at Newcastle Mines Rescue Station (NMRS) and the School of Mining Engineering at UNSW (UNSW) could be migrated to the advanced system.

The project had a total budget of $1715600 over three years with a later commercial component of $250000 to produce more content.

Core project aims were to,

- Build and maintain an internal module building capability,
- Use off the shelf software and hardware,
- Produce photo-realistic simulations
- Have in place a sustainable commercial footing for the long term development of immersive, interactive simulations at the end of the project (or be very close to achieving this).

The benefits of VR simulation are described in earlier VR simulation projects funded by Coal Services that have demonstrated that immersive, interactive VR simulations provide for more effective education, training and assessment in OH&S (Fowler et al 2005).

The project aims were to immerse trainees in a multitude of realistic mining environments and engage the trainees during the simulation session. The interaction with the simulations and the 'scenarios' would be drawn from the core competencies for mine workers.

This report reviews the progress made during the three year project and presents data acquired during that period and also a business case for the continuation of the project longer term.

Project Objectives

The primary objective of the project was to develop an enhanced 'State of the Art' VR capability in immersive, interactive, virtual reality simulation based on the findings of Stothard and Galvin (2005).

It was envisaged that the primary objective would be realised by deploying 'State of the Art' technology to Coal Services through NMRS in order to improve OH&S management and performance in the Australian coal mining sector by providing training tools that lead to more effective education, understanding, training and assessment. The VR capability would allow NMRS to 'expose' trainees to hazardous mine working situations and assess safety procedures - all within a safe classroom environment.

The enhanced simulations would take advantage of features such as curved screen technology identified by Stothard and Galvin (2005) that utilises the user's peripheral vision and thus increases the feeling of immersion in the virtual environment. One of the main aims being to expose miners to a high resolution 'one to one' virtual reality representation of the mine environment.

Greater use of industry expert input would also be used to increase the reality, relevance and decision points included in the simulation program. The use of industry experts was considered essential for the project for acceptance by the industry and the sourcing of high value industry experience to be placed into the simulations.

It was planned to continue to develop two existing simulations, Rib and Roof Stability and Unaided Self Escape to improve their relevance and content through industry expert input to increase the realism, relevance and the decisions made in the simulation program during runtime. A number of new simulations were also to be developed based on the outcomes of strategic planning workshops.

The secondary objectives of the project were to include,

- Providing an opportunity for the Mines Rescue Service to grow another business stream to support its activities.
- Utilising the technology to improve the effectiveness of undergraduate and postgraduate teaching and research in minerals related areas. VR allows the mine to be brought to the classroom.
- Continue to take mining engineering education and research into a cutting edge field.
- Providing a working demonstration of the software and hardware technology that may be applied to other activities of the coal mining industry and other industry sectors.
- Build a library of modules.

State of the Art

The ‘State of the Art’ of VR technology was reported by Stothard and Galvin (2005) via an International Scoping Study that included a visit to fifteen VR research and development groups around the world. The study showed that interactive virtual reality technology is extremely well developed. Almost any environment can be simulated to a high level of resolution, fidelity and interaction. The study confirmed the advantages of VR simulation identified in earlier projects, namely the following outcomes to be achieved (Table 1 and 2):

Visualisation of the hidden	Evaluation of the consequences of decision-making
Visualisation and communication of the complex	Developing understand and retention of learning
Visualisation of the future	Customised ‘on the job’ training in a safe and forgiving environment
Flexibility in time and place of learning	Tracking of learning progression and understanding
Hazard spotting	Equipment assembly and maintenance training
Faultfinding	Accident investigation and reconstruction

Table 1. Outcomes of VR Simulation

The above are reasons why VR simulation finds increasing application for situations where:

The environment has to be entered before it can be properly ascertained	A degree of skill is required in order to execute the response to the environment
The environment is susceptible to dynamic change	Laypersons are involved in making judgments about events that have occurred in one of these ‘hidden’ environments
Human decision-making plays a critical part in responding to the environment	

Table 2. Benefits of VR Simulation

At the outset of the Enhanced VR project in 2005, simulations could cost from $10K to $1M and complete purpose built ‘reality’ centers in the order of $15M.

Cost is a function of the level of complexity of the virtual environment content and more fundamentally, the cost of the visualisation hardware and its configuration.

Mine scenarios written to operate on the advanced hardware present highly complex environments and tasks for simulation development, particularly underground coal mine environments and this is explained in the AusIMM Future Mining Conference paper presented in Appendix A. The classification of systems and information that can be presented on them will assist in developing new modules and enhancing the current modules further.

Project Plan

A broad project plan was developed to steer the project. The initial Gantt chart is shown in Table 2 and 3. The key areas of the project are defined in bold and were altered somewhat as the project developed in order to keep the project fluid and able to adapt to the needs of CSPL and MRPL. Some key aspects were fast-tracked and some reduced in importance as the project progressed and more experience was acquired. Key major components were,

- Detailed project plan and identify resources
- Acquire industry input
- Educational evaluation of current modules
- Equipment purchase and evaluation,
- New simulation modules – (note longwall change out was superseded by other content development).
- Install curved screen system
- Develop a Business Plan
- Assess potential collaborators models and transferability.
- Perform a formal assessment of the training module packages and modify according to NMRS requirements.
- Place project on a self sustaining basis according to the business plan.

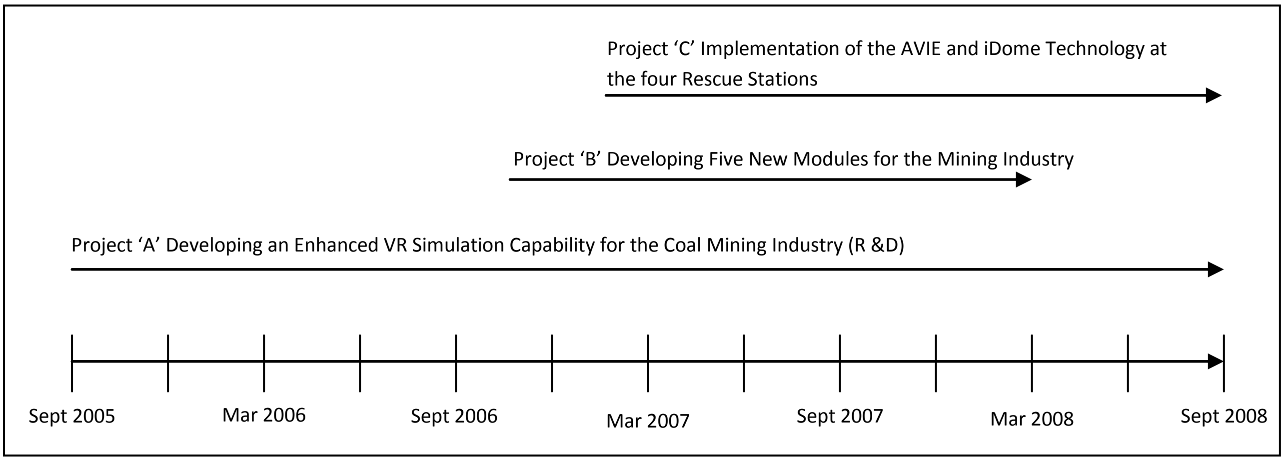


Figure 1. Timelines of the three VR projects (Dates are approximations)

Key outcomes were to establish a strong and maintainable capability for the development of VR simulation technology and place the development and implementation of the systems and the programming of content on a sustainable basis derived from a robust business plan. The project plan of Table 2 and 3, is only used for reference as the project was significantly impacted upon by the fast tracking of the 160 screen acquisition and the subsequent iCinema AVIE and iDomes. The result of this fast tracking was that three projects ran in parallel.

- Project 'A' Developing an Enhanced VR Simulation Capability for the Coal Mining Industry (R &D)
- Project 'B' Developing Five New Modules for the Mining Industry
- Project 'C' Implementation of the AVIE and iDome Technology at the four Rescue Stations

Running projects in parallel was not an ideal situation however the outcomes and achievements were outstanding. The overlap and inevitable impact of the projects is shown in Figure 1.

ID	ℹ	Task Name
1		**Coal Services VR Simulation Project**
2		**Year 1 Objectives Reporting Quarterly/ Presenting as Required**
3		**Device Project Detailed Plan and Identify Resources**
4		Strategic Project Plan
5		Identify and Confirm Project Contributors
6		Confirm Project Objectives
7		Develop Primary Business Plan
8		Begin detailed financial assessment and identify target markets
9		Detailed Assessment of Previous VR Project NMRS and UNSW
10		Assess status of existing model objects
11		Perform standardisation and polygon reduction on existing models
12		**Industry Input**
13		Identify and Contact Industry Experts
14		Identify Suitable Modellers (eg Continuum)
15		Identify Suitable Programmer (eg Albert Cheung)
16		**Educational evaluation of current models**
17		Develop learning outcomes for interaction with VR models
18		Modify Existing Scenarios to Meaningful Simulation Training Packages
19		Perform Pilot Training Session For Evaluation
20		**Equipment Pre-purchase Evaluation**
21		Initial Equipment Purchase
22		Curved Screen Purchase
23		**New simulation models**
24		Begin Longwall Change Out Simulation - Development

Table 2. Project Plan

ID	ℹ	Task Name
25		**Year 2 Objectives Reporting Quarterly/ Presenting as Required**
26		Build and Install new Curved Screen Facility at NMRS or SMRS?
27		**Develop Secondary Business Plan**
28		Refine financial assessment and target markets
29		Begin to produce models commercially
30		**Assess collaborators VR models and transferability**
31		Assess possibility of industry standards for model building protocols.
32		Instigate collaborative database of mine equipment objects
33		**Model Migration**
34		Self Escape Model - Migration to New System
35		Rib Stability Model - Migration to New System
36		Refinement of Longwall Change Out
37		**Demonstrations**
38		Present New Simulations and Technology to Industry Personnel to Generate Interest/Business
39		Present New Simulations and Technology to Educational
40		Present to International and National Community
41		Stress test VR Models in Industry
42		**Perform Formal Assessment of Training Packages and Modify according to CS/NMRS/ Educational Requirements**
43		Refine simulations according to feedback
44		Bench Mark the System
45		**Year 3 Objectives Reporting Quarterly/ Presenting as Required**
46		**Modify VR training modules according to previous two years data**
47		Refine educationally sound VR simulation models according to bench mark
48		Set up system for turn key operation (train the trainers)
49		Add new function / delete inappropriate function
50		Stress test VR Models in Industry
51		**Place project on self sustaining basis according to the business plan**

Table 3. Project Plan...continued.

Core Team Development

One of the keys to the success of the original project was the planning of the project in a manner that allowed a process of continual improvement to be made during the life of the project. Running projects under such a research and development program facilitated continual improvement during the life of the project and also provided increasing momentum to the core group as they became more experienced in simulation development. The initial plan is shown in Table 2 and 3. The key resource for this type of project is people with the requisite skills to produce the simulation content. The requirement for people with the necessary skills to build successful and meaningful simulations cannot be understated. The project required and included people from a broad spectrum of backgrounds that when combined formed a highly effective team.

To develop interactive VR software simulations that are tailored to the specific needs of the New South Wales Coal Mining industry, it was realised from earlier projects that the task of research, development and deployment requires skills and knowledge outside of that normally found in Mining Engineering disciplines such as the UNSW School of Mining Engineering. One of the key objectives of earlier projects was to have mine trainers or mine engineers develop simulations themselves. Unfortunately, this task is generally outside the horizons of most mine personnel and specialist capabilities and skills are required. The earlier projects developed for CSPL were successful however, continuous industry engagement was difficult primarily due to the nature of the new technology and its applications not being understood. Also, the techniques used to develop the simulations were still new and required refinement. Examples of the first simulations are shown in Figure 2. The figures are included here to present a baseline from which resolution and fidelity were to be increased.

Figure 2a. 2004 Unaided Self Escape Module

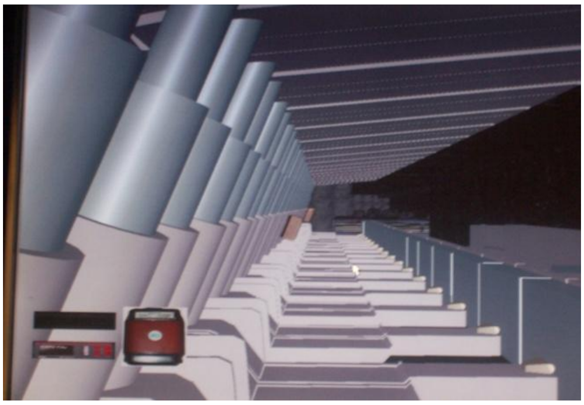


Figure 2b. 2004 Longwall Model

The 'Enhanced Mining VR Project' (Project A) would demonstrate the improvements in the visualisation of the models resulting from the use of a more diverse team. The images of Figure 2 were built by mining engineers and researchers with limited industry input and while they were advanced for their time, particularly with respect to having an interactive virtual environment, they still required some work to lift them to a higher level. To lift the model building process and improve the relevance and interaction of the modules, it was realised that a more diverse team was required. The key people for this team must be drawn from the following disciplines and provide the services outlined in Table 4.

Person	Tasks	Background	Quantity
Project Consultant	Liaison with industry experts and development team	Experienced Researcher and Technology Transfer Expert. Experienced Project Manager and Simulation Developer.	1
Project Manager	Liaison and management of the development team, scheduling of tasks and monitoring of progress	Experienced software development manager with ability to prioritise and motivate the development team to completion of the tasks and also motivate the providers of industry input to the project to ensure efficient collation of information during the module building process	1
High Level Industry Board Members	Ensure that the scope of the project is realized by the client workforce and to manage change at its facilities	Experienced board member used to dealing within the dynamic industry environments. Visionary in their view of the future of the industry	1
[1]Industry Experts	Provide experience and knowledge of mine training procedures to the development team both directly and indirectly	Experienced Mine Workers Managers and Deputies Broad experts with varying knowledge and willingness to experiment with a new technology	4
3D Artists	Provide the capacity to build photo realistic mine models from photos and plans acquired from industry experts. Ability to conceptualise mine working from underground and surface visits, acquire data and convert these to a photorealistic representation	Graduate Artists trained in the latest 3D visual effects that can be generated using industry standard 3D modeling software such as 3DS Max or Maya. The artists also have training in media acquisition and production of animated sequences for placement in the virtual world.	4
Computer Programmers	Provide the capacity to program the necessary interaction into the 3D model. Leverage games engine technology and develop new interactive techniques.	Graduate computer engineers and scientists. High level of programming capability and ability to develop new concepts and utilize the off the shelf programming environments to their maximum potential.	3
Educational Specialists (Mining)	Provide structure to the VR modules and ensure that they relate to the core competencies for mine workers	Mining Industry Educational Experience and Competency Based Training expert	1
Educational Psychologist	Provide methods to assess the effectiveness of VR training and enhance its capability and implementation within the training program	Graduate Psychologist	1
[2]General Contractors	Install and provide technology support for the VR systems	Computer suppliers and engineers	10
[1]Note. This number reflects the ‘single’ point of contact. Several others are behind this number. [2]Note. This number is variable depending on the scale of the project			

Table 4. Summary showing the diverse nature of the team required to implement and maintain the enhanced mining VR capability.

Table 4 shows that the team that is required to develop content for the coal mining industry is diverse. The skill set for each person or group of people is essential for the production of high quality simulation material. The liaison and logistics of managing the team is a complex issue and the communication bridge between client and developer is fundamental to the production process. The mining experience provided to the developers is also significantly enhanced when the developers are provided an opportunity experience the real mine environment first hand.

Argenton160 Degree System

The selection of technology for the Argenton site was based upon the findings of Stothard and Galvin (2005). The format and installation of a spherical curved screen based upon the concept seen at Railcorp at Petersham in Sydney. The system was driven by Silicon Graphics machines and had been in use for several years at Petersham and was to be supplied by VR Solutions of Brisbane who also installed the Railcorp screens (Figure 3).

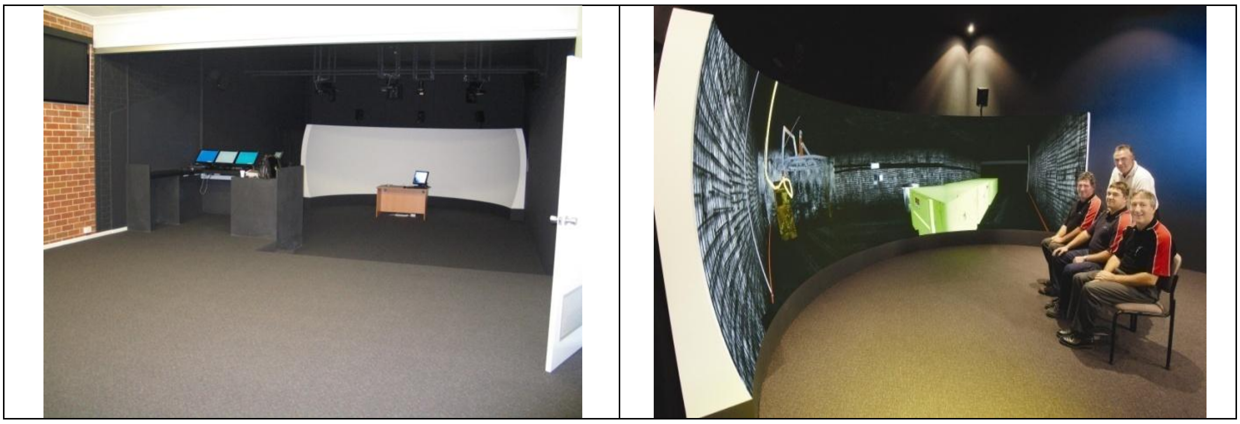


Figure 3: Argenton Simulator Hardware, Mono, Spherical Screen Concept.

The system was selected for NMRS in consultation with CSPL for the following reasons.

- The system already existed and was being used to train people in the rail industry that had a similar demographic to the NSW coal mining industry. Members of CSPL and MRPL visited the site and were impressed by the technology and could see its application to mine training.
- The system presented a large image that provided 'one to one' scale for the user.
- When the user is sat at the design eye point (see figure 4), the image on the spherical screen appears to completely surround the users vision.
- Large groups can also experience the simulator by observing the operators actions in a theatre environment.
- The use of a spherical mono screen meant that there was no requirement for stereo imagery and when operated from design eye point, the user's eyes are focussing on the screen at a fixed distance.
- The system could be easily modified to accept both a Silicon Graphics Unix/Linux based system or a PC based cluster system.
- Real machine controls could potentially be interchanged at the design eye point to allow the configuration of the system to take 'anyone's' content or controls. This was considered important from the point of view of providing the system with maximum flexibility and ensuring that it could be used to its full potential.
- The system was available with a high quality service agreement that allowed the system to provide a very high level of availability to the Mines Rescue Service at Argenton.

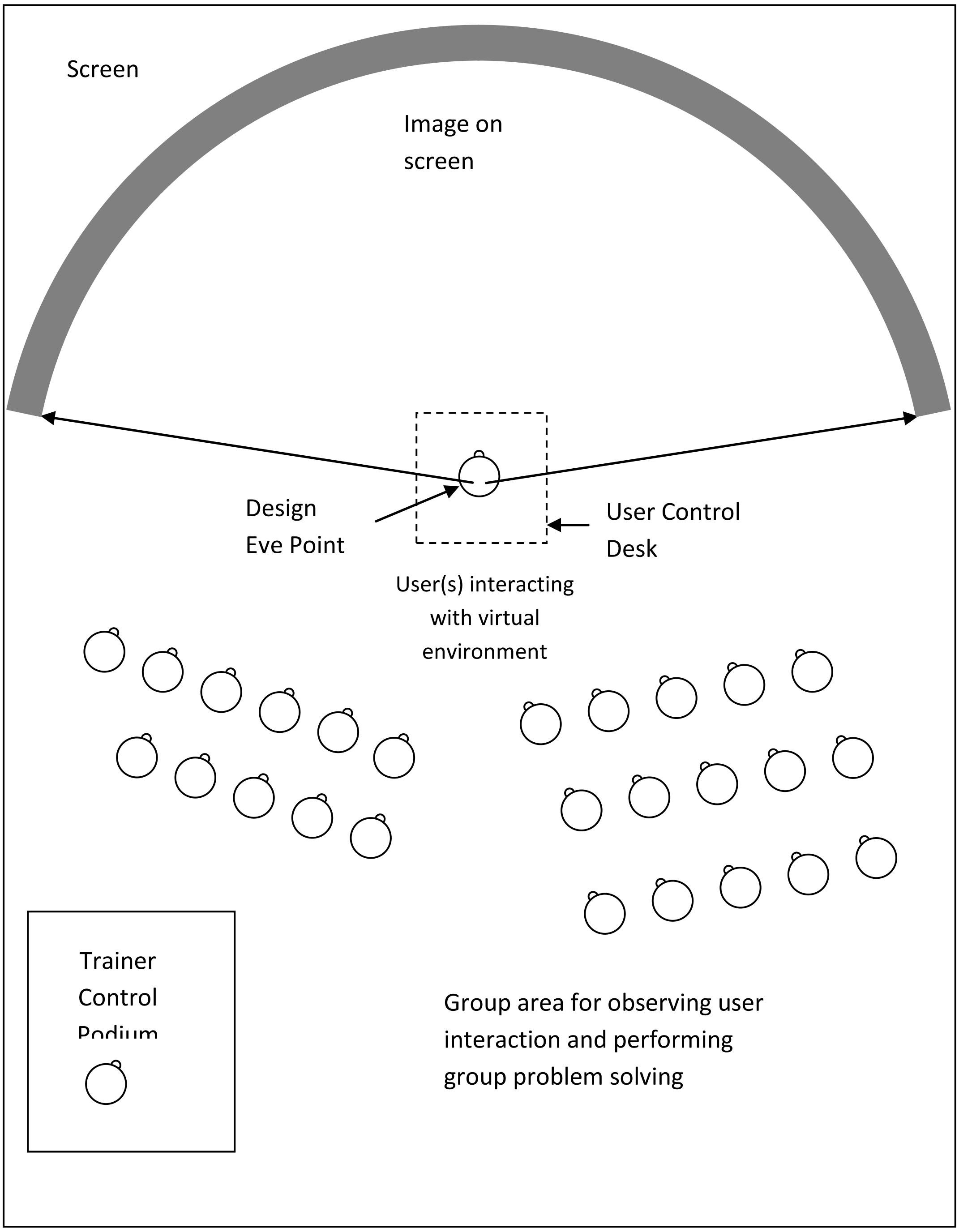


Figure 4: Plan View of the Argenton 160 Degree Spherical Screen Immersive VR System.

The installation of the visualisation system at Argenton required a large space to be identified at. One of the criteria that the MRPL management considered a priority was the selection of an unused space that when renovated would add to the capacity of the teaching space at MRPL. Hence, to accommodate the visualisation system, an unused gym and swimming pool area was identified as having suitable space for housing the proposed spherical screen of the 160 degree system.

The installation was placed in this space as it was an area where research and development could be performed that would not impede the daily activities of NMRS, however, from day one of commissioning, the screen was in regular use and R&D was difficult to implement on site. The squash court is shown in Figure 5.

Figure 5a. Renovation of the NMRS Squash Court

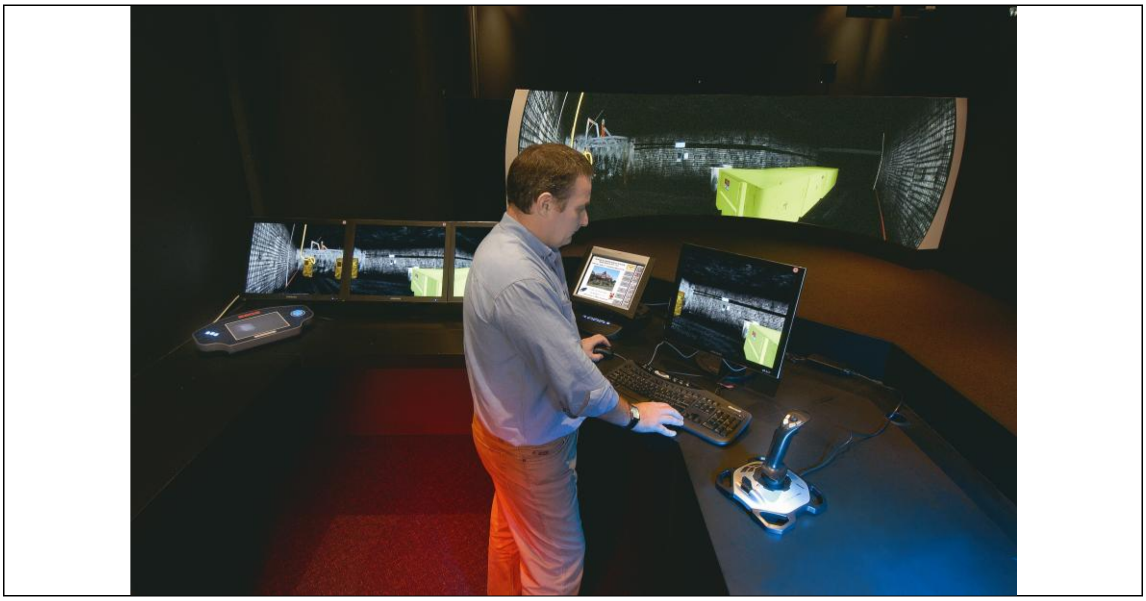


Figure 5b. The completed system and first images on screen

During the specification of the room and screen, sufficient data cabling was included to ensure that subsequent updating of interface controls could be accommodated. The building and conversion works were carried out over the first six months of the project with the conversion being complete by March 2006.

The system was formally opened by NSW Premier Morris Iemma in September 2006.

This system has proved to be very successful and has been in daily use since its commissioning. Within the first 12 months, several hundred trainees had experienced simulations on this system. This number is increasing over time.

3D Modelling Software

The 3D Modelling software that was used for the development of models was 3DS MAX produced by Autodesk (http://usa.autodesk.com).

3DS Max was used because it is an 'industry standard' modelling package that has a wide user base and contains many functions that allow the development of photo realistic textures for modules. Also, as one intention was to re-use many of the assets acquired in earlier projects, the licenses available to the project were still current and would only need to be upgraded to take advantage of the developments in 3D modelling and rendering techniques. Additional commercial licenses were purchased during the project.

The 3DSMax software was also very close in function to MAYA also produced by Autodesk and similar in function. Both 3D Modelling programs were used extensively by the UNSW College of Fine Arts, CSE, Mining and many other 3D modelling courses that develop 3D Artists. Taking this approach ensured that a steady and consistent flow of 3D artists was available to the project that had the capabilities described in Table 2.

An example of the 3DS Max Modelling environment is shown in Figure 6.

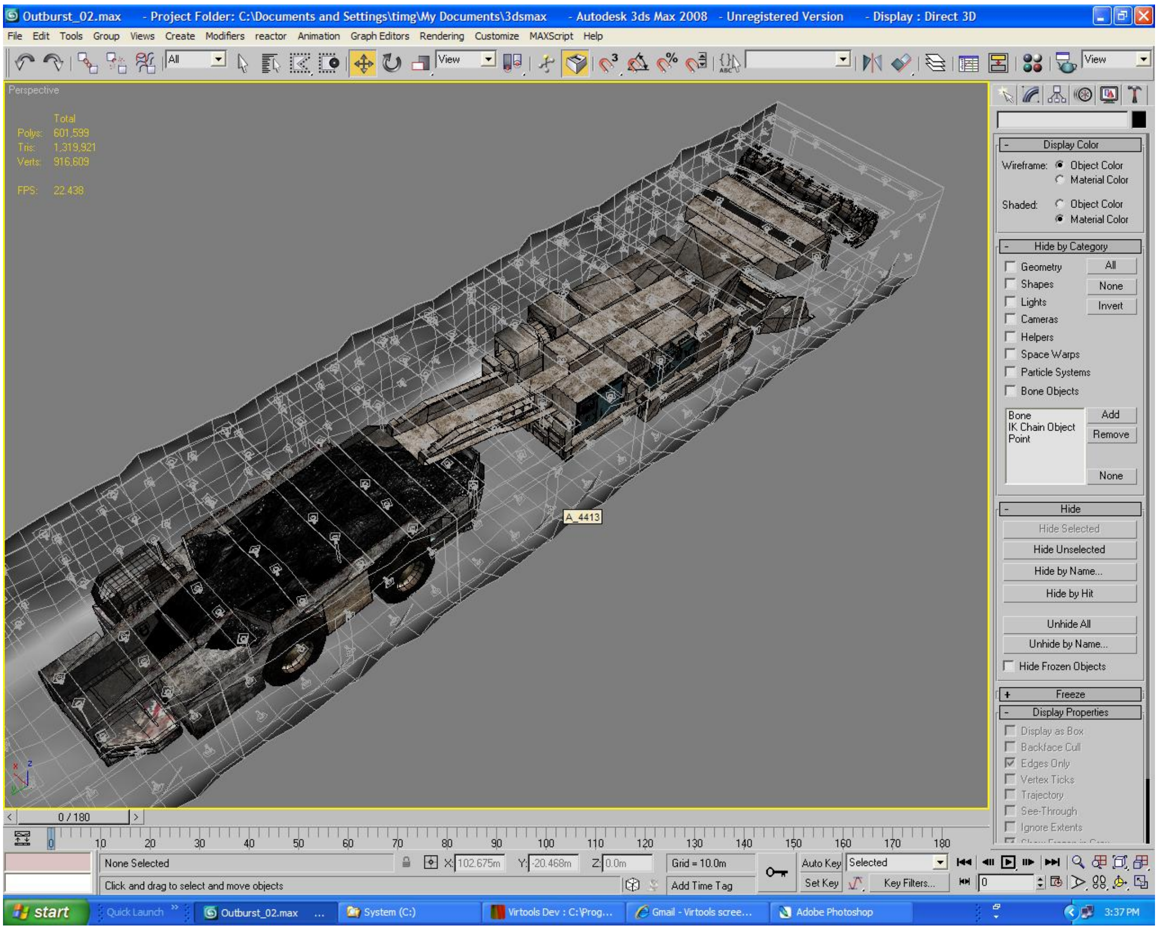


Figure 6. 3DS Max Programming Environment

The models produced were also able to benefit from both the 3DS Max tools that enable high resolution images to be constructed and also intricate animations to be produced.

Interactive Programming Software

The earlier projects utilised the SAFE-VR program developed by AIMS in the UK. However, this software was found to be limited and unavailable for the new project. Hence the interactive programming software that was chosen for the interactive display environment was Virtools. (http://www.virtools.com/). Virtools was chosen as previous projects had shown that the use of a drag and drop interface combined with a command line programming interface allowed the project team to leverage both the highly developed programming experience of the computer programmers on the team and also the less developed programming experience of some of the 3D Artists who had programmed using scripting languages in the past (Figure 7). A fundamental to successful VR is maintaining control of the development process. This has been maintained through the use of this type of software.

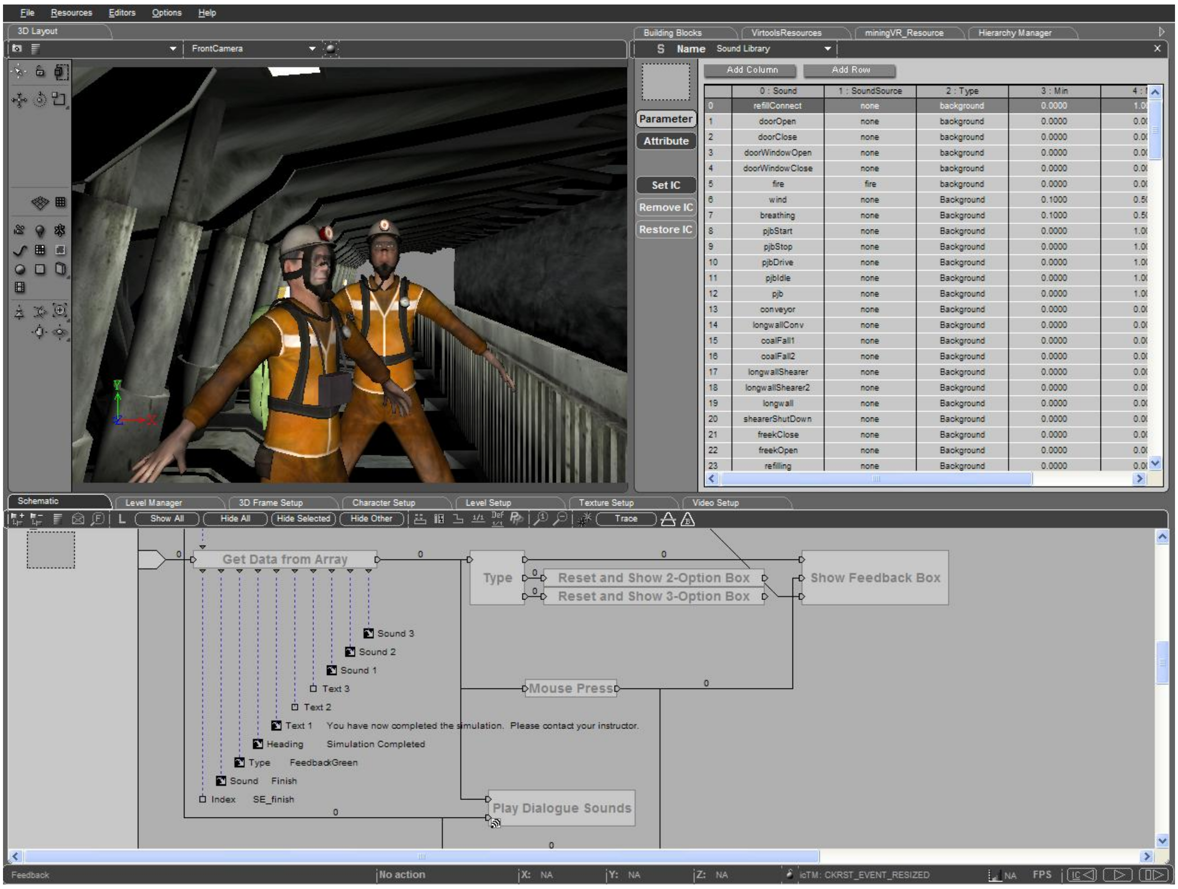


Figure 7. Example 'drag and drop' programming interface in Virtools.

The selection of the Virtools software that was used to build the modules and program the interaction within them was also made on the basis that it could support clustering of PCs. Under the 160 degree system, the system uses a cluster of four PCs, one is a master machine and the other three are slaves. Each slave runs a single projector (Figure 8). The clustering of PCs was essential for producing large scale curved images for the 160 degree screen. Image blending was performed in hardware by the VRS/SEOS system.

Alternative software considered for this task was Open GL Performer, VR Juggler, VRCO, Toucan and EON, however, due to a combination of the time constraints due to fast-tracking of the project, cost and the availability of a cohort of readily trained and available programmers at UNSW who would form the inhouse team, Virtools was the preferred option. The selection of Virtools also coincidentally fell in line with the work of iCinema who were developing the AVIE system that became the next generation visualisation system.

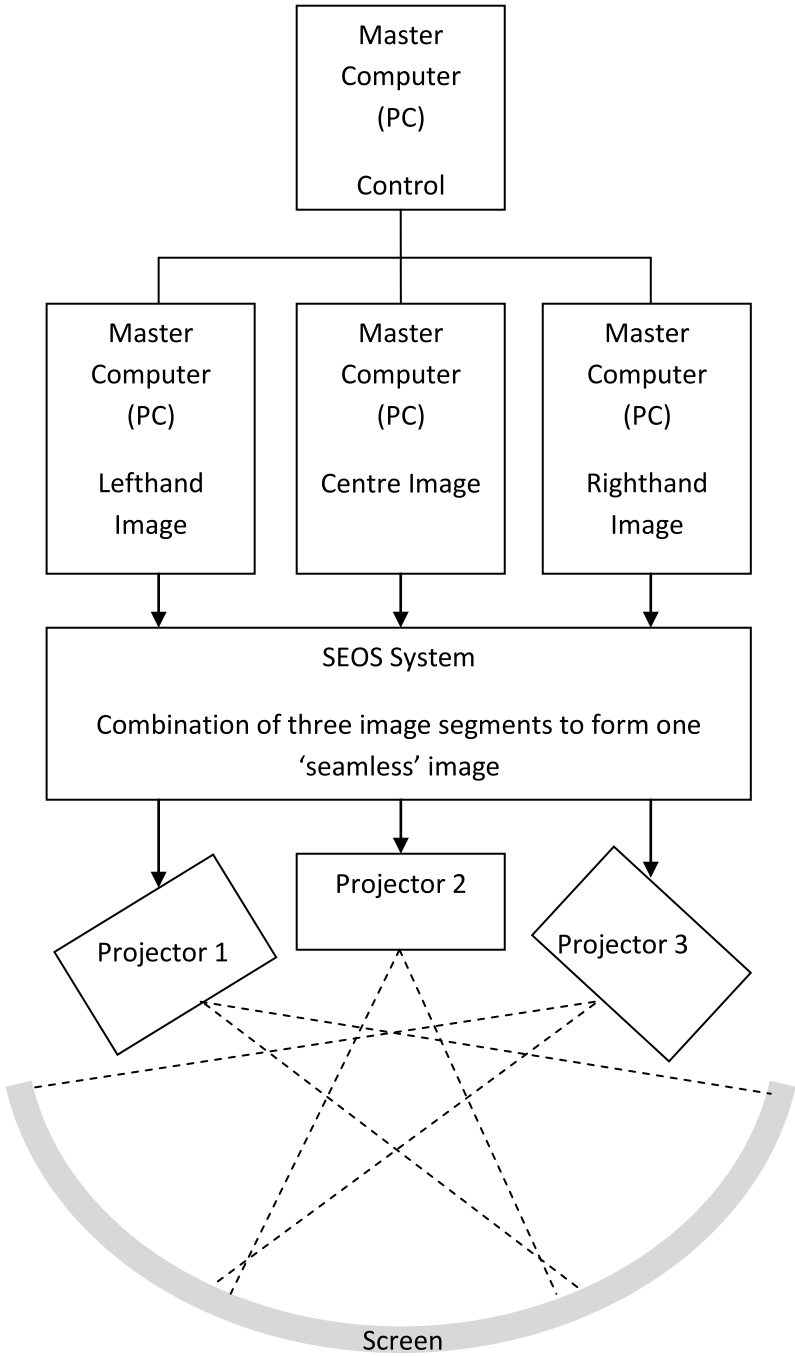


Figure 8. Basic architecture of 160 degree system.

The use of Virtools also allowed the rapid development of scenarios to be developed as an iterative process in consultation with CSPL and MRPL. Building blocks that were developed for interaction and animation could also be utilized between modules.

Module Development

3D Modelling

The development of the three prototype modules that were developed for the project as 'proof of concept' were generated over several months as part of an ongoing process of improvement. The Mining VR team from UNSW met on a regular basis with the industry experts provided by CSPL and MRPL. The process is shown in Figure 9.

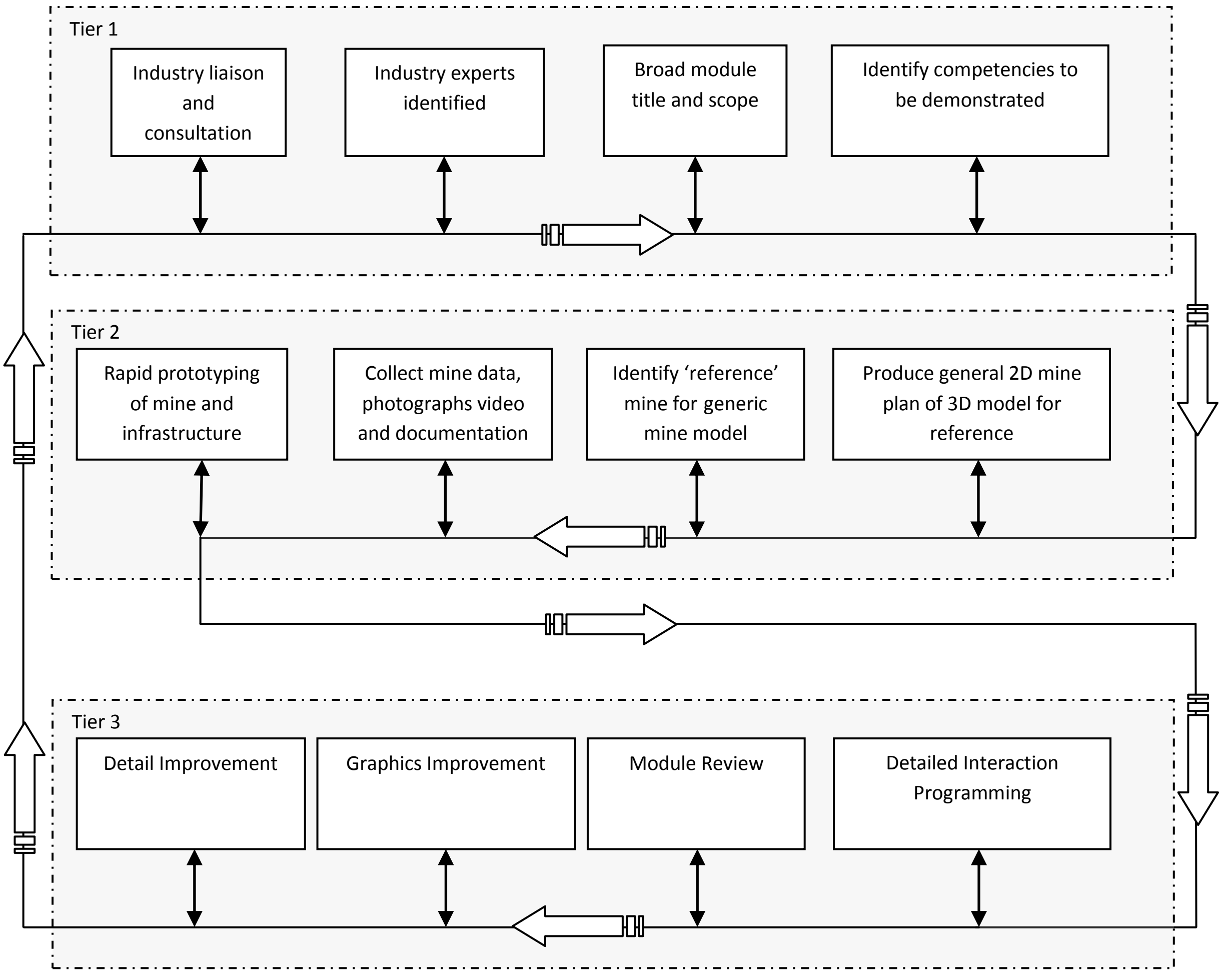


Figure 9. Module development process.

The module development process requires that a specification for the modules be developed. However, at this early stage, it was difficult to quantify the exact specifications of the modules as the concept was still new to industry. Hence, the first stage was to ascertain what the industry required and it was decided that the three prototype modules would be Unaided Self Escape from a long wall coal mine, Rib and Roof Stability and Truck-Pre-Shift inspection. The next stage was to indentify industry experts to help plan out the module and formulate the interaction so that it would cover the core-competencies for coal mining relevant to each module. In the case of Unaided Self Escape and Rib and Roof stability, the Coal Training Package MNC04 was referred to. In the case of the Truck Pre-shift Module, an onsite walk around inspection course was the foundation for the module. Once the broad scope of the modules was agreed, a 2D plan of the mine model was drawn by the industry expert and in the case of the underground modules the mine was sectioned into 5m sections within the 3DSMax modelling package. An example mine plan section is shown in Figure 10 and the resulting model shown in Figure 6.

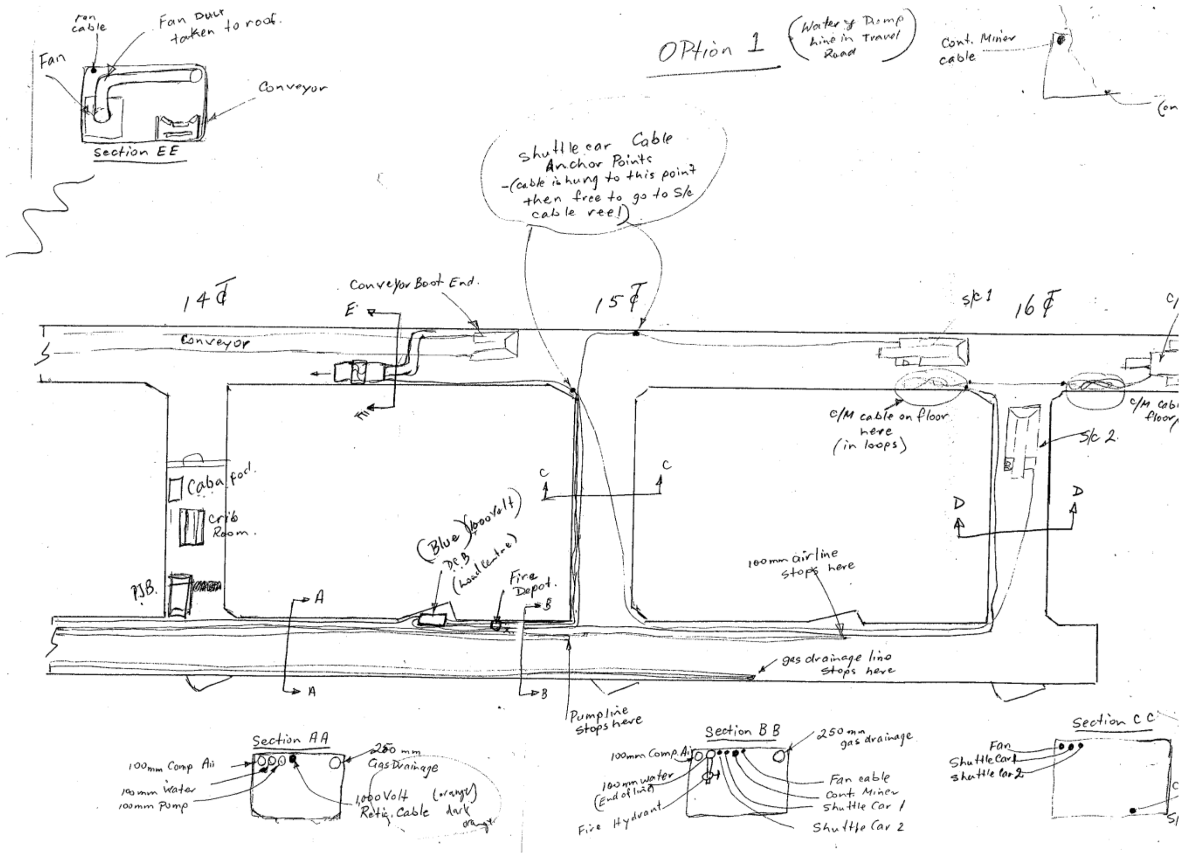


Figure 10. Example section of complete mine plan showing locations of infrastructure.

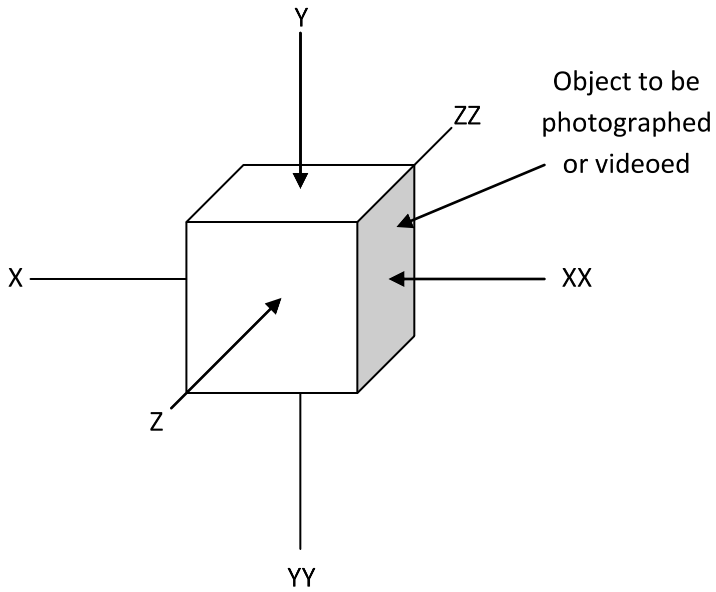
The short mine section shown in Figure 10 is a small segment of a complete mine developed for Unaided Self Escape and Rib and Roof Stability. In subsequent modules, a similar mine plan was produced for a complete long wall mine and a five heading development panel. The decision to section the model into short 5m sections was made for the following reasons.

- Constructing the model in 5m sections would allow the model to remain modular and enable components of the complex geometry to be switched on and off by the image generators (computers) when not within the field of view of the user. This is important for reducing the amount of computing overhead within the simulation and maintaining sufficiently high frame rates so that the model runs smoothly at run time.
- A suite of 5m sections could be constructed and different bolting patterns and noise could be introduced to reduce the repetition within the simulation and make the mine appear more realistic to the user.
- Different rib and roof textures could be applied to various sections of the mine to reflect a specific mine as opposed to a generic mine. For example, in the southern region of NSW, the ground conditions are different to the northern region.
- Local infrastructure and equipment could be placed within the sections and different lighting conditions could be applied.

- Corners and breakouts could be replicated at differing levels of 'correctness' within the simulation.

The above description relates to the generation of the mine environment and the static infrastructure such as ribs, roof, pipes, conveyors and so-on. However, there are also dynamic systems placed within the environment, such as a continuous miner, shuttle car and stone dust fan. Each of these systems required detail reference for model building and also animation. This involved the collection of detailed photographs by mine experts and the modelling team. Collection of the correct photographs became highly important as the tendency was to photograph what interested the collector of the photos, or to simply photograph everything.

The method for collecting photographs had to follow the procedure shown in Figure 11 to be successful.



At least three levels of detail should be taken in each direction.

1. Low showing the whole piece of equipment.
2. Intermediate showing the equipment close up.
3. High showing close up equipment in detail

Figure 11. Photo and video acquisition.

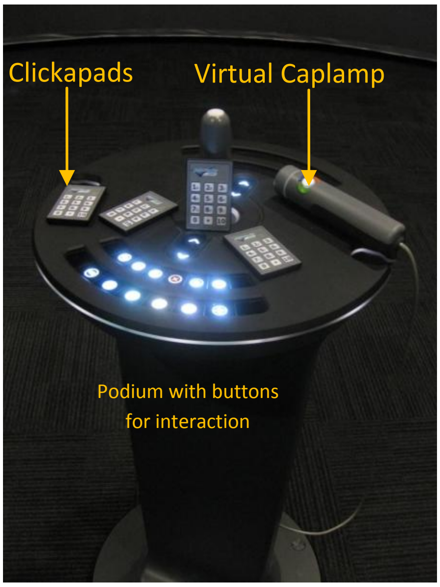
To collect effective images that can be used for reference, the object, for example a continuous miner, should be photographed from the positions, X, XX, Y, YY, Z, ZZ, where possible. Images should also be taken at different distances from the equipment so that different levels of detail are captured in the images. This is particularly relevant as the 3D modellers often have no idea of the use or function of the equipment and are merely building the models as they see them. Manufacturer's design drawings are also very useful for the development of equipment models as these can have their polygon count reduced to ensure efficient rendering inside the module.

All images collected by the various team members are placed within a repository for future use in subsequent modules. These images become useful assets for reference and are placed in a repository for later reference.

Modules Interaction

One of the key objectives of simulation technology is to allow users of the virtual world to interact with the environment and learn from it. Without interaction, the system is passive and hence the user could potentially navigate around the world and learn nothing. To ensure that the user considers his or her actions and hence interaction, a series of question and answers are presented to the user or group.

The questions are derived from the core competencies that relate to the scenario and to demonstrate understanding the user must select the correct answer. The structure of the questions was carefully worded by the industry experts and mine trainers so that the correct information is elicited from the system. Interaction with the module is via Virtual Caplamp and a Clickapad (Figure 12).



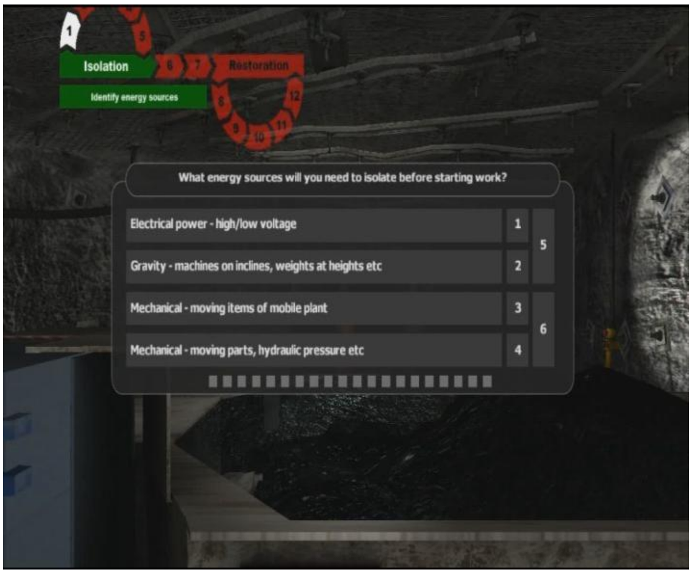


Figure 12. Interactive devices and example question and answer.

Depending on the context of the training, the user can also navigate the environment using a joystick or 'hop' from point to point using a shortcut key on the podium. The interaction with the modules is recorded by the machine to a database. Each Clickapad is assigned to an individual and the responses relating to interaction are recorded to a database. This database can then be interrogated by the trainer as part of the formal assessment process. However, at this stage, the database and feedback is rudimentary and interrogation needs to be formalised. This is a task for a later project.

Virtual models of instruments have also been developed that allow the user to take readings in the virtual environment. Examples of the instruments are a Velometer used to check the air flow at the face adjacent to the continuous miner and also a Multiwarn instrument that is used in several scenarios to evaluate the condition of the atmosphere in the Spontaneous Combustion Module.

Data produced by these instruments appears on the screen to the user in real time and hence the user can determine the significance of readings in real time and decide upon a course of action. The subtlety of the readings can be changed to reflect the experience of the user.

Modules Developed and Deployed

The original "Developing an Enhanced VR Simulation Capability for the Coal Mining Industry" project (Project A in Figure 1) and the subsequent extension of the project under a commercial contract (Project B) produced eight Modules in total. These fall into two categories, of 'Proof of Concept' and 'Production' respectively. However, in fact all eight modules are developed to a level where they are used for formal training. Brochures for several of these modules are shown in the Appendix B.

Proof of Concept Modules

Truck Pre-shift Inspection,
This module is based on a Truck Pre-shift inspection at a Hunter Valley Coal Mine. The aim of the module is to allow the trainee to walk around the truck and identify maintenance issues and hazards associated with the truck prior to driving the truck up to the shovel.

The module has approximately 40 hazards and these are randomly loaded.

The user also has to confirm that the correct personal protective equipment is being worn by the operator. Figure 13

Figure 13. Screenshot of Truck Pre-shift Inspection

Rib and Roof Stability,
This module is based on the navigation of a two heading long wall development panel. The objective is for the user to begin at the crib room and receive instructions from the Deputy.

The user then has to navigate around the panel and observe the rib and roof conditions. During this navigation, the remedial action required to ensure that the area is safe must be observed otherwise the user will either be shown the consequences of not adhering to the safe work procedure, or will be reprimanded by the Deputy.

The module contains a continuous miner and two shuttle cars and the user must also interact with these in a safe manner. Figure 14

Figure 14. Screenshot of Rib and Roof Stability

Unaided Self Escape

This module is based on the procedures for Unaided Self Escape from a longwall mine. The module requires the user to react to a cap lamp signal, contact the control room and follow instructions.

The sequence of events in the module require the user to evacuate the longwall team by donning the self contained self rescuer (SCSR), checking gas levels, navigating to the compressed air breathing apparatus (CABA) and changing over from SCSR to CABA.

The user must follow the primary egress and evacuate via the CABA refill stations, navigate a roof fall and also the fire on the belt. The objective is to reach fresh air. Figure 15.

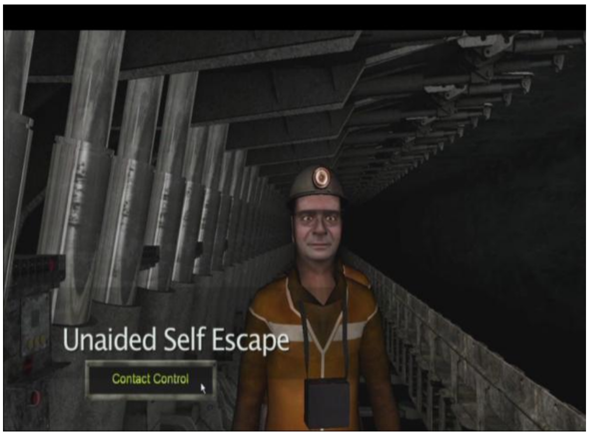


Figure 15. Screenshot of Unaided Self Escape

Five Production Modules

Under and extension of the original project and a new commercial arrangement, five new modules were

Hazard Awareness

This module presents the user with a five heading panel based on Mannering Coal Mine. The user navigates the mine on a pre-set route and must interact with the environment to spot hazards. The hazards range from missing guards to moving vehicles and airborne dust.
Subtle hazards such as build up of coal under the belt and water at the face are also included. Figure 16

Figure 16. Screenshot of Hazard Awareness

Isolation

This module introduces the concept of isolation of equipment around the five heading panel. The module is sectioned into seven sub modules that deal with issues such as isolation of the feeder breaker, fire line extension, LHD hydraulic hoe replacement and so –on. The module includes a graphical representation of the twelve step isolation process. Figure 17.

Figure 17. Screenshot of Isolation Procedure

commenced in 2007. These modules were originally planned for the Argenton 160 degree system only.

Spontaneous Combustion

This module presents a complete longwall mine from face to portal and includes bleeders behind the workings. The objective of the module is to present the user with a set of data relating to gas readings around the mine that may be an indication of a Spontaneous Combustion Event. The user selects a heating and is taken to the start point. Using the multiwarn, the user takes readings and determines where the heating is located. Figure 18.

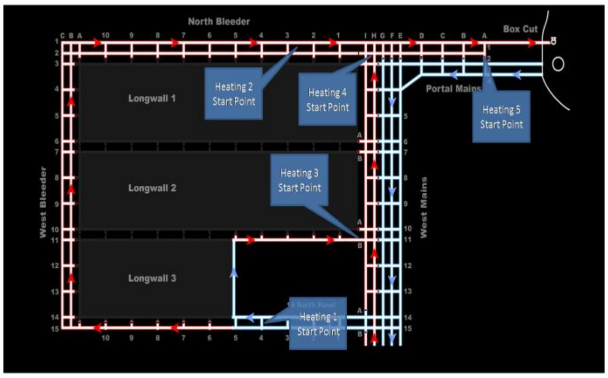


Figure 18. Spontaneous Combustion Heatings

Deputies Check Inspection

This module presents the user with the user with a working panel where the workers must be assigned tasks after the user has made a check inspection. The user must demonstrate the optimum route to take to the face to take in the maximum amount of equipment. Sufficient materials to perform the job must be confirmed and the user must also respond to several emergency scenarios. Figure 19.

Figure 18. Deputies Inspection

Gas Outburst

This module deal with the phenomena of gas outburst that can occur in some coal mines as a discontinuity is mined towards and stress in the surrounding coal is released from solution. The even shows the out burst quite graphically which gets the user's attention. The outburst could be avoided and this is conveyed to the user. A sequence of indicators must be identified during the scenario and information on these is purveyed to the user. Figure 20.

Figure 19. Buried Shuttle Car

The modules were built in consultation with industry experts and were also programmed to be scalable. That is, with minor re-adaption, the modules can be placed on any platform ranging from a normal laptop PC with a reasonable graphics card through to a full scale AVIE system with complete 360 surround image. Achieving this is not a simple task and considerable behind the scenes adaption of the module formats had to be programmed to take advantage of all platforms. The process for this adaption is now complete and the modules can be potentially be run at any MRPL site on any platform. Also, an important factor for consideration is that the modules can be output as interactive or non-interactive video so that sections or cameo pieces of one scenario can be brought into another scenario. The video clips can also be used as online training materials. In total, MRPL have approximately 12 hours of content that could be shown and significantly more if 'mixed and matched'.

Educational evaluation of current modules

The educational evaluation of the group of modules has been informally made by the development team industry experts and NMRS. That is, the modules are set up to provide scenarios that cover core areas of competence. However, a more formal evaluation is ongoing and being performed by UNSW School of Mining as a Masters Project. It has been difficult to acquire a reliable person suitable for running this formal evaluation. This person has now been found and collection of data runs past the end of this project and will be made available to CSPL in late 2009. In the interim, feedback from CSPL and MRPL is continuing through the support services agreement that accommodates small changes to the interaction and operations within the modules. The model for the educational evaluation that will be performed is outline as follows.

Experiment to asses educational outcomes

The project will be conducted in conjunction with the School of Mining Engineering at the University of New South Wales (UNSW), which has developed a variety of VR simulations for use in mining training. It is thought that by engaging trainees in a more interactive simulation that is visually representative of their work environment, they are more likely to benefit from the training process. The simulation allows a “greater understanding of the mine environment hazards, procedures and day to day operations” in a real mine (Stothard, Mitra, & Kovalev, 2008). Thus, it has been suggested that an increased level of human interaction would lead to greater learning. In this case, human interaction is measured by levels of immersion and presence.

Immersion is described as the “subjective experience of being in one place or environment, even when one is physically located in another” (Witner & Singer, 1998). Immersion is measured via the Immersive Tendency Questionnaire (see materials section below) and consists of 29 items that relate to the main factors of Focus, Games and Involvement. Participants rate their answer on a 7 point Likert scale. For example, for the question ‘Have you ever gotten excited during a chase or fight scene on TV or in the movies?’, participants have the options of 1 = never, 4 = occasionally, 7 = always.

Presence is described as “experiencing the computer generated environment rather than the actual physical locale” (Stothard et al, 2008). Presence is measured via the Presence Questionnaire (see materials section below) and consists of 33 items that relate to the main factors of Control, Sensory, Distraction and Realism. Like the Immersive Tendency Questionnaire, participants rate their responses on a 7 point Likert scale.

Spatial awareness is defined as an ‘organised awareness of the objects in the space around us, and an awareness of our body’s position in space’. It requires the individual to have a model of the three dimensional space around them, and the ability to integrate information from all their senses. The spatial ability test to be used will be provided in due course.

Each participant will be measured on each of the following four Dependent Variables:

Immersion	Presence	Spatial Awareness	Level of Learning

Each participant will be placed in one of four visualisation platforms, and they are described below:

AVIE 360	Room 148	PC	iDome
Group learning in the VR simulation	Large flat screen for group learning	Flat screen, individual learning in front of a computer	Individual learning in the VR simulation

The final design of each study will be:

Individual factors / Learning (Environment)	Immersion	Presence	Spatial awarenes
AVIE 360			
Room 148			
PC			
iDome			

Summary of Hypotheses

Hypothesis 1. It is expected that users' level of immersion will be positively correlated with their level of engagement and thus lead to better learning. However, it is possible that users enjoy the simulation because of greater engagement but are not more likely to absorb the material.

Hypothesis 2. It is expected that users' level of presence will be positively correlated with fidelity, or screen size and visual environment. Specifically, as proximity to screen increases, users report higher levels of presence. This positive correlation will be present for both mining and non mining groups.

Hypothesis 3. It is expected that as level of presence increases as a function of visualisation platform, learning (as measured by number of answers correctly reported) increases, showing the transfer of educational outcomes has occurred. Simple comparisons should be run between the different visualisation platforms to work out differences.

Hypothesis 4. It is expected that as level of spatial ability increases, users are more likely to demonstrate a greater level of learning because they have greater spatial awareness. This will enable us to examine if individual differences in spatial awareness affect learning in the VR simulations. Specifically, users with natural spatial abilities will be more likely to perform well in the VR simulation training.

Hypothesis 5. It is expected that as the level of spatial awareness reported increases, it will lead to higher levels of immersion because users are more likely to engage with the VR simulation.

Hypothesis 6. It is expected that as level of spatial awareness reported increases, level of presence reported increases because the user is better able to engage with the environment as he or she is more aware of the 'space' around them.

Hypothesis 7. It is expected that transfer of learning occurs as a result of the VR simulation, and this is shown by an increase in scores on the knowledge test administered at the end of the training.

Design

Two studies are proposed. The first study will be conducted on participants with no mining background, while the second study will be conducted on trainees from Coal Mines in NSW, Australia. Both studies will be similar in design, and the hypotheses apply to both studies. The analysis of both studies will involve correlation analysis, namely to test the relationship between the variables a) immersion b) presence c) spatial awareness and educational learning outcomes. Simple one way ANOVAs will be run to compare the groups across the different visualisation platforms.

Participants

Participants for Study 1 will consist of 80 – 100 students from the third year psychology course 'Behaviour in Organisations'. During Week 4- 5 of semester 1, they will participate in the study as part of the games and training component, which will constitute a portion of their course requirement.

Participants for Study 2 will consist of 100 trainee miners from Coal Mines in NSW, Australia. They will complete the module as part of their training course.

Materials

Immersive Tendency Questionnaire (ITQ). This questionnaire was developed by Witmer and Singer (1998) and has been widely used to measure factors related to users' sense of presence in the VR simulation. The ITQ is normally completed by trainees prior to observing the simulation. Factors that are measured by the ITQ include a) involvement: tendency to become involved in activities; b) focus: tendency to maintain focus on current activities and games; c) games: tendency to play video games.

Presence Questionnaire (PQ): This questionnaire was also developed by Witmer and Singer (1998) and is normally completed by trainees after being in the VR simulation. The PQ measures major factors that relate to the trainee's perception of the display system features. This includes Control Factors, Sensory Factors, Distraction Factors and Realism Factors. The Table 5 shows the factors hypothesised to contribute to a sense of presence.

Table 5. Factors that contribute to a sense of presence (Witmer, Jerome, & Singer, 2005)

Control Factors	**Sensory Factors**
Degree of Control	Sensory Modality
Immediacy of Control	Environmental Richness
Anticipation of Events	Multimodal Presentation
Mode of Control	Consistency of multimodal information
Physical environment modifiability	Degree of movement perception, Active Search
Distraction Factors	**Realism Factors**
Isolation	Screen realism
Selective attention	Information consistent with objective world
Interface awareness	Meaningfulness of experience
	Separation anxiety/ disorientation

Spatial Awareness Questionnaire. Spatial ability will be measured with the use of a spatial visualisation test. (This test to be used has not been confirmed as yet).

Knowledge and Engagement Questionnaire. This test will consist of a variety of questions which will measure the education outcomes of the VR simulation. It will consist of mainly multiple choice questions and will include questions relating to users' level of engagement with the VR simulation.

Demographics. Participants will be asked to complete demographic information relating to: gender, age, educational attainment and location.

Procedure

The procedure for Study 1 and Study 2 will be similar, except that they will be conducted at different locations. Participants will be invited to complete the spatial ability questionnaire. After that, they will be asked to complete the Immersive Tendency Questionnaire. Participants get a 10 minute break before they have a 20 minute theory lesson. Thereafter, trainees get 15 min in the simulation. Different groups will be placed into the four different visualisation platforms, namely the AVIE 360, Room 148, PC and iDome.

Following the simulation, participants have to complete the Knowledge and Engagement Questionnaire. After that, they are asked to complete the Presence Questionnaire and fill in their demographic information. Focus groups will be run for Study 1 involving the students at UNSW to allow them to express their opinions of the simulation and offer avenues for improvement.

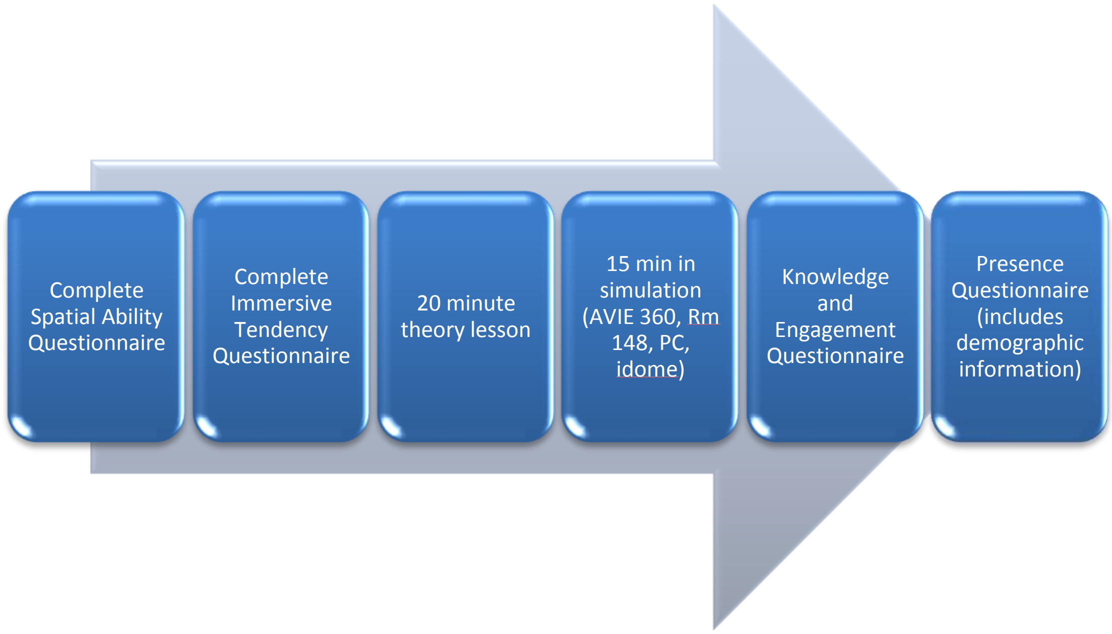


Figure 20. Experimental procedure flow chart

A pilot study of this experiment has already been performed at Argenton and had some encouraging results. The results are presented in the paper ' Assessing Levels of Immersive Tendency and Presence Experienced by Mine Workers in Interactive Training Simulators Developed for the Coal Mining Industry ' in Appendix D.

Perform a formal assessment of the training module packages and modify according to NMRS requirements.

The formal assessment of the modules was performed via an ongoing liaison with CSPL and MRPL. The review of the first three modules developed as proof of concept leveraged five new modules that increased in complexity and sophistication throughout the project. This increase in sophistication is shown in Figure 21 . The educational evaluation described earlier is separate to this more operational evaluation and is continuing. However, the two will evaluations will compliment each other.

The current simulation module (or content) development process consists of several key components as shown in Figure 8. These are industry expert interview & 'instruction', data collection & database development, educational theory, 3D model building and interaction programming. The key components all feed into the module content. Users and experts then use the module and provide feedback into a process of continual improvement.

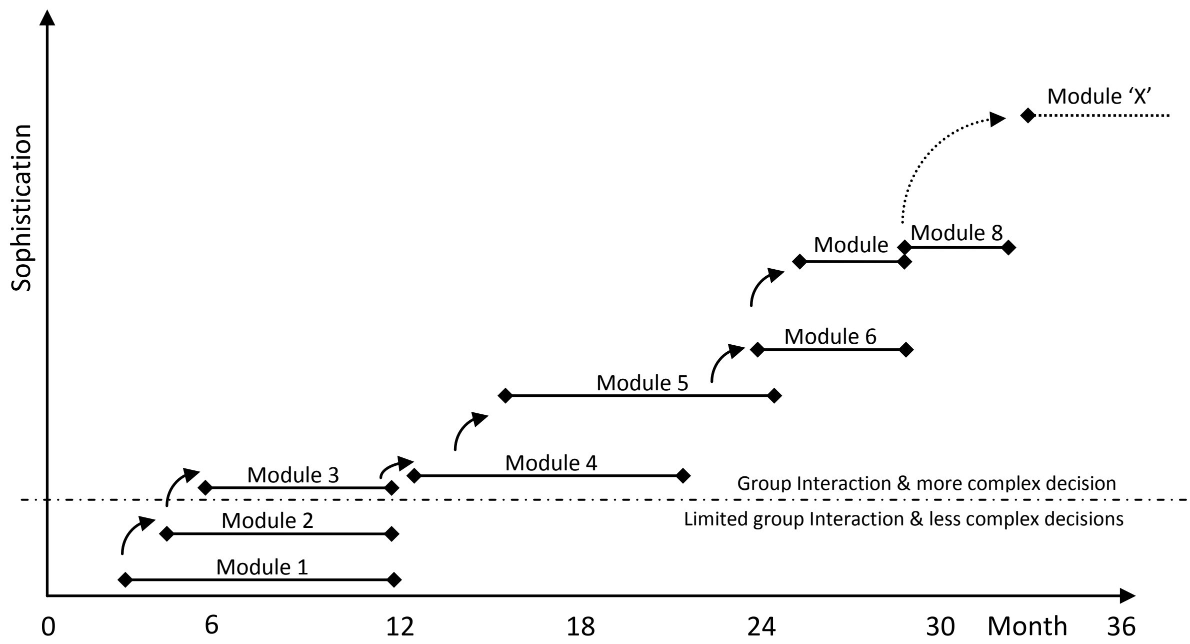


Figure 21. Improving the sophistication within the modules over time.

In the underground modules developed by UNSW, the environments are based around a real coal mine and extend from coal face to portal. Each module's key objective is to provide trainers and trainees with a high resolution virtual mine environment in which procedures and processes relating to the module disciplines can be practiced while the trainer and trainees navigate the environment. The development process shown in Figure 8 has proven effective in module development and module content has benefited from the process of continual improvement. Overtime, developers and industry experts have become gradually more experienced and have more content at their disposal on which they can build and refine further content. The increasing sophistication of the module content over time is shown in Figure 21. Over the project, the more sophisticated content and the time to develop has decreased to less than six months, however, the content in later modules is more comprehensive and the interaction more complex so the point of inflection may not yet be reached. The time frames do reflect ‘blank software’ to fully implemented simulations and include the time to collate and review information and refine the simulation via iteration.

The modules have moved from simple navigate. Though point and click to interact. To collect data, analyse data, make informed real time decisions and present a solution to succeed. Trainees navigate the environment as a group of ideally five to six people. However, larger groups can be accommodated. During navigation around the mine environment, the trainees are presented with tasks that must be identified and remedied according to safe work procedures and safety management plans pertaining to that environment or situation.

The learning process in the environments is at present ‘learning by doing’ as described by Dewey (1939) and cited by Johnson and Rickel (1998). Essentially trainees are given a task to complete and they demonstrate competency by answering a series of questions relating to the issue. An example question that appears in the isolation module is shown in Figure 12. Trainee responses are recorded by the system and at the end of the session they receive a statement of their level of achievement. In practise, this is similar to the apprentice method where the incumbent is initially given a closely monitored task and as experience is gained that need for supervision or monitoring diminishes and eventually the apprentice works unaided. At present the modules only go a part way towards this and the trainers guide the trainees quite closely.

Assess potential collaborators models and transferability.

The use of collaborators modules in this project was found to be ineffective due to the rapid nature of the model building and the commercialisation of the project in the form of the five new modules.

The issue of model sharing has been discussed several times with the International Mining VR group www.vrmining.org and unfortunately, this has not proceeded due to concerns with copyright, ownership of modules and licensing issues.

In theory competitors models could be used. In practice this may be too cumbersome to manage.

This is an area that the International Mining VR Group will continue to work on.

At present, it is preferable that UNSW and CSPL produce their own 3D models.

Trainee Experience in the 160 Degree System:

Level of Presence

Training mine workers in the real environment is extremely difficult due to safety and logistical issues. During training, it is important that miners are provided with information, knowledge and experience of the mine environment in which they will work so that they can build up and demonstrate competency. The ideal training situation would be an exact copy of the particular mine environment in which miners will operate. On a small generic scale this is practicable, however, producing a complete representation of every mine into which groups of trainees can be placed is less so and it is difficult to alter these physical mines quickly and easily so that subtle and significant differences between one mine site and another can be represented. High resolution virtual mine training environments provide the flexibility to achieve the required look and feel of specific mines.

Also, the requirement for trainees to feel immersed and experience presence – that is, "The subjective experience of being in one place or environment, even when one is physically located in another" is considered important as the miners need to gain experience that translates to the real world. In the virtual environments produced for this project, presence refers to experiencing the computer generated environment rather than the actual physical locale. In this case, the environments are computer based virtual mines. Until recently, training of mine workers was performed by conventional training media, such as PowerPoint presentations, videos and lectures interspersed with limited hands on training. These techniques are not always the most efficient for learning and can interfere with learning if inattention is allowed. It is believed by the authors and literature that a strong sense of presence is linked to the quality of training. An objective of the UNSW/CSPL mining project is to provide a sense of presence to mine workers during training so that they feel as though they are underground and not necessarily in a classroom environment. The need for such a high level of presence is required for two reasons, the first is that trainers require a high resolution mine model in which trainees can be placed that looks and reacts as a real mine would. The second is that many highly experienced miners can provide high level experience that can be placed into the model environment. This experience must be recorded for future generations of workers, however, to extract the subtle details that are important to ongoing safety, the experienced mine experts must see the model as a real mine and experience presence to accept it as a training tool and be able to conceptualise mining practices – good and bad that are to be placed in the virtual mine for training purposes. Many features are small scale and it is proposed that high levels of presence will improve the experience given to the mine workers and experts with respect to these issues in particular. Another key issue is the practicality of some mine safe work procedures, which as the project progresses are manifesting as impracticable. These processes are now being reviewed by mine experts who can now collaborate in the virtual environment to improve these procedures. Spatial awareness in the mine environment is also a key factor relating to safety where large machinery and unstable ground is often encountered.

The results of the experiment to survey levels of Presence and Immersive tendency are presented in the Paper in Appendix C. The results were presented at SIMTECT 2008 by Stothard, P., Mitra, R., & Kovalev, A. (2008). The conclusions from the experiment were as follows.

Mining is a high risk industry that requires highly trained and experienced personnel to maintain safety standards. However, gaining experience in real mines exposes people to risk. Virtual training environments provide a safe and forgiving environment in which experience, knowledge and skills can be obtained. Practising these skills leads to and maintains competency. Conventional classroom methods work under many circumstances, but in some instances they are inappropriate and allow inattention by the trainee. Their effectiveness is also sometimes questioned. As a process of continual improvement, UNSW has developed interactive virtual training environments into which groups of miners can be placed to learn and build up experience of mining environments. To provide the high levels of interaction and transfer of knowledge from industry experts and trainers to trainees, high resolution virtual environments are required and high levels of presence are required to make the trainees feel as though they are underground while in fact, they are actually at a Mines Rescue Training Facility. To begin to assess the level of presence and immersive tendency experienced by the trainees during virtual mines training sessions, an experiment was performed based on established procedures. These procedures were implemented relatively unchanged to demonstrate repeatability and subsequently showed that they were in fact highly repeatable. The experimental results showed that mine trainees who viewed the simulations did experience high levels of presence and had immersive tendencies that caused them to be involved, focussed on the simulation and become immersed in the environment. The correlation and presence were in many cases higher than the original work. However, this may be due to the demographic of the data set. While the system of assessment for the tasks is still being developed, anecdotally, the trainers report a more meaningful experience is presented to the trainees in the form of a visualisation of the underground environment. This in itself may be the reason for a higher level of presence and immersion and will be tested in future work. An interesting feature of the data is that the mine workers surveyed, don’t really read books or watch TV. Given that current training methods rely on text and videos in PowerPoint presentations etc, it would appear that a more interactive approach to training that involves and immerses trainees in the virtual environment is more likely to successfully transfer knowledge and skills and improve long term safety.

The analysis of presence will continue under the educational evaluation of the project.

Journal Publications

During the course of the project, three papers have been written and presented. Two International Mining VR Workshops have also been held. In general, UNSW and CSPL are in front of the other providers of simulation to industry however, there are some serious competitors as would be expected, especially in the commercial sector where training organisations are making rapid acquisitions of off the shelf technology that may not be an exact fit for their needs. Many of these competitors are described in the business plan located in Appendix C.

The completed papers are presented in Appendix A and D.

Business Model

Setting up the infrastructure and team to produce the models, bringing them together with the necessary industry expertise with the capability to produce meaningful models and actually producing the models to the required standard is a major achievement and despite losing some personnel over the course of the past three years, a core group has been maintained that can maintain the support and development of modules into the future. However, over the life of the project, there has been significant development work done to provide this foundation and many processes have been developed by the team. These processes are continually refined however they are no longer in the realms of 'pure' research and must be moved into a more sustainable vehicle that can manage the routine development of modules and allow the assets generated by previous projects to be leveraged as much as possible in new modules. To achieve this, a business model was developed that demonstrates the core team required for a sustainable module development business and the estimated costs involved. The business model is a hypothetical one with some future predictions. The full plan is shown in the Appendix C and should be considered as an example only. More accurate modelling is required for any formal business.

Executive Summary

Since the VR projects began back in 2000, the University of NSW's School of Mining Engineering has developed the Know-How to create high-quality customised Virtual Reality Training Simulations and Visualisations that improve safety training for occupations in unsafe situations and environments.

To establish the effectiveness of the Know-How the School has formed the VRGroup to research, develop, implement and test Virtual Reality (VR) Training Simulations and Visualisations.

The VRGroup has proven the effectiveness of the Know-How by creating eight underground mining training modules and a growing digital asset library. These are now part of the VRGroup's Intellectual Property and can be licensed to future clients by either CSPL or UNSW(NSi).

The VRGroup's Simulations enable organisations to train their staff to recognise hazards, observe possible consequences and take corrective action in a safe, risk-free environment carefully designed to produce better learning outcomes than conventional training methods.

These Simulations have been successfully implemented and tested in very demanding conditions, indicating the potential for the VRGroup to become a commercial business.

The initial service offering targets the training organisations that service the mining industry. This is an area in which the VRGroup has already established itself, with products already in service and future orders in hand.

A critical success factor for the VRGroup is the ability to access essential information about workplace environments and equipment. This access can only be gained through the co-operation of industry, and is difficult to get without industry support.

Until recently the technology used to create and display VR content has been unable to deliver quality high enough to satisfy industry. With the support and resources of the University of NSW the VRGroup is at the forefront of emerging technologies, using the latest 3D software applications to provide high-quality Simulations that provide the trainee with a realistic experience and adds significant value to the training process.

The VRGroup's revenues will be generated through:

- Custom Modules: Customised training modules designed to faithfully represent a specific environment and training situation, created with new material supplied by the client. Where possible the VRGroup will retain the rights to the material it develops so that it can be re-used to create Generic Modules.

- Generic Modules: Combining material previously produced for other projects with assets from its growing digital library the VRGroup will produce Generic Training modules (with some customisation) at a much lower cost than fully customised modules.
- Licensing Models: Licenses will be negotiated for both Custom and Generic training modules, on an ‘annual’ or ‘per-user’ basis.

An initial analysis of the financial viability of this venture shows outstanding results and promise. The market for Advanced Training Simulations such as those offered by the VRGroup is significant.

Two options for incorporating the Know-How into a commercial venture are:

- As a standalone business: The financial projections included with this plan assumes that the VRGroup will become a standalone business with no external support from a parent company. This option requires a very senior manager (Managing Director) to manage the business full time.

  Detailed financial projections are included in the appendices of this plan. The following is a summary of those projections (for a standalone business):
- As part of a larger business: If the VRGroup were to become a Division of a larger company its costs would be lower - it would not require a full time Managing Director, for example, and would be able to share some of its expenses, such as occupancy and other costs, with its parent.

  As a Division of a larger company the VRGroup would also benefit from the relationships its parent already has with key industry groups, increasing its speed to market and lowering risk.

The business plan relates to placing the existing development team on a commercial footing and identifies the key people and enablers to generate a self-sustaining business. The projections are purely speculative and refer only to the production of content for the various VR platforms. The complete ***example*** business plan is shown in Appendix C. This plan may form the basis of a more formal business model.

Project Funding

The funding for the project 'Developing an Enhanced VR Simulation Capability for the Coal Mining Industry' was kept within budget and fully expended. The budget was enhanced by the addition of funds for the development of five new modules on top of the original three modules.

The development of the five modules and their conversion to the multiple platforms did impact on the budget, however, the overall outcome was positive and all the modules and their conversion to the new platforms developed by iCinema was covered by the projects.

The total project value was $1715600 for the three year project and $250000 for the five modules.

Funding and progress schedules were presented to CSPL during the project.

The total funds for the project are now expended and all tasks complete.

When this budget is considered in total for what has been achieved and compared to the games industry cost of developing a computer game, the cost is very reasonable.

Conclusions

The project 'Developing and Enhanced VR Simulation Capability for the Coal Mining Industry" has been successful.

The project has resulted in a 160 degree curved screen being implemented at Argenton Mines Rescue Station and the system is in daily use.

The system was installed in a space at Argenton Mines Rescue Station that maximised the useful teaching areas available by converting a little used gym and squash court.

A core team of programmers and 3D artists were brought together with mining industry experts and highly sophisticated simulations were developed.

The system was installed to accommodate the UNIX and PC based systems. However, the PC system prevailed.

Three 'proof of concept' modules were developed to a high standard and implemented under the fast tracking of the project.

Five additional modules were developed under an additional commercial arrangement that drew on more industry experience.

Two commercial projects ran in parallel in the second 18 months of the project with obvious impacts. However, the outcome was successful implementation of all three projects.

The project remained fluid throughout its duration that allowed changes to the system(s) and the modules to be made 'on the fly' as no formal specifications were available. The modules were also re-configured to run on the platforms purchased subsequent to the 160 degree systems.

A great deal of know how on how to produce modules tailored to the NSW coal mining industry has been acquired and this is presented in an example business model.

The modules have been tested by trainers and industry experts and also assessed for their impact on trainees. Trainees enjoy the modules and trainers now have an accurate visualisation to show trainees. The modules are also interactive which engages the trainees in the training module via and interactive virtual torch and Clickapad session.

The formal evaluation of the educational outcomes from the modules still requires further work and a suitable person to perform this work has now been engaged. The data collected by this person will be confidential and made available to CSPL over the coming months.

Several papers and presentations have been made on the project and the consensus is that CSPL and UNSW have developed a high end, high quality training tool. The content developed for the visualisation systems has application in other industries.

The project is not yet set up for commercialisation. However, all the components are there and continued work on enhancing VR for the NSW Coal Mining Industry should continue under a predominantly commercial footing. Routine module production should only continue under this arrangement.

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Appendix A: Taxonomy Paper

Taxonomy of Interactive Computer-based Visualisation Systems and Content for the Mining Industry - Part 1.

Taxonomy of Interactive Computer-Based Visualisation Systems and Content for the Mining Industry – Part 1

P Stothard[1], A Squelch[2], E van Wyk[3], D Schofield[4], K Fowle[5], C Caris[6], M S Kizil[7] and M Schmid[8]

ABSTRACT

This paper has been written collaboratively by members of the International Mining VR Group. It is the first of two papers.

Mining in the 21st Century is an industry that strives to reduce risk and improve safety through the use of improved processes and procedures. This risk reduction process is aligned with the innovative use of technologies often developed for other industries. Computer-based visualisation systems and their content are such innovative technologies, in particular the use of virtual environment systems and mixed reality. A primary object of developing virtual environment systems and the mixed reality content displayed in them for the mining industry is to allow mine workers and operators to practice mine processes and demonstrate competency in tasks that will be encountered in day-to-day mining operations at mine sites. It is anticipated that providing easy access to virtual environment systems will facilitate the avoidance of high-risk situations through improved knowledge, skills, understanding and decision making. Via virtual environment systems mine workers will also be able to practice infrequent or emergency events and maintain preparedness for such events. Day-to-day mining practices can also be evaluated. The rapid pace of technology innovation and the decreasing cost of simulation hardware and software present a plethora of technology to the uninitiated. This can be confusing. In this paper taxonomy is presented that classifies hardware, what it can display and also content that can be included or displayed on the various computer-based visualisation systems. The taxonomy provides insight into where technology can and may be implemented in the future as virtual environments are a dynamic and evolving technology. The taxonomy should also assist in the decision making process when scoping or selecting technology for a particular purpose.

INTRODUCTION

Mining in the 21st Century is a high technology industry that strives to reduce risk and improve safety through the use of improved processes and procedures. This risk reduction process is aligned with the innovative use of technologies often developed for other industries. Interactive computer-based visualisation systems and their content are an example.

Modern simulation systems range from tactile systems that physically represent the real world through to purely computer generated visualisations. These computer-generated, three-dimensional, artificial worlds are commonly referred to as virtual environments (VE) and in many instances people are able to interact with the data and images that are presented by these computer-based visual systems.

In a mining context, a primary aim of developing virtual environments is to allow mine personnel to practice and experience mine processes that will be encountered in the day-to-day operations at a mine site. In today's industry, safe and efficient planning and production is fundamental to profitable mine operations and virtual environments provide an intuitive means of exploring the diverse and disparate information associated with mining processes.

It is anticipated that providing easy access to virtual environments will facilitate the avoidance of high-risk situations through improved knowledge, skills and decision making in the workplace (Tromp and Schofield, 2004). An advantage is that mine personnel are also able to practice seldom experienced scenarios, thereby maintaining a level of preparedness and developing their knowledge and experience. In addition, routine mining operations can also be developed, practised and monitored in virtual environments.

International and domestic collaboration between mining industry experts, engineering, computer science and arts has also significantly impacted on the delivery of such technology to the industry, with several systems now in place around the globe. System format is variable and even with readily available virtual environment software and hardware it is sometimes it difficult for organisations to locate the appropriate technology and identify a solution for their particular needs. More fundamentally, technology is no longer a barrier and the focus is now moving towards the meaningful representation of data and interactive content.

In this paper, a taxonomy is proposed that broadly classifies the wide range of interactive computer-based visualisation technologies that are available to the industry. Many already exist, however, some are still to be realised. A number of interaction metaphors are also discussed and the taxonomy provides insight into where these systems may be implemented. This paper is part one of a series of papers. Further papers deal with a number of real-world case studies demonstrating the application of this technology within the mining industries.

TERMINOLOGY AND DEFINITIONS

There is a plethora of visualisation technology and computer-based visual content that is commonly referred to as virtual reality or simulation.

In an attempt to quantify visualisation systems, their uses and implementation, the authors present and define some common terms derived from Milgram and Kishino's (1994) virtual continuum and the broad terms of reference for other descriptors.

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All real and synthetic aspects of real and virtual environments fall somewhere along the virtual continuum and many of the terms presented by Milgram and Kishino (1994) continue through to today. However, others have become synonyms. Mixed reality is a term presented by Milgram and Kishino (1994) that is all encompassing and spans much of the virtual continuum of Figure 1.

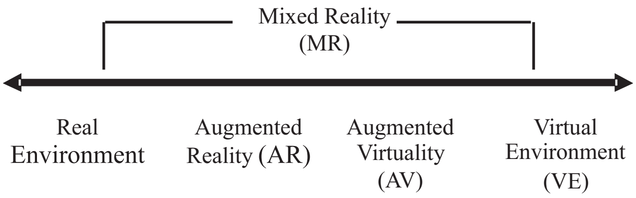

FIG 1 - Virtual continuum (after Milgram and Kishino, 1994).

Reality

Reality, in everyday usage, means 'the state of things as they actually exist'. The term reality, in its widest sense, includes everything that is, whether or not it is observable or comprehensible.

Augmented reality

Augmented reality (AR) refers to the overlaying of real-world imagery with computer-generated data. As an intermediate case in the virtual continuum of Figure 1, it refers to predominantly real imagery where virtual elements, eg computer-generated objects, are dynamically overlayed within the display. AR research is concerned with the use of live video imagery which is digitally processed and 'augmented' by the addition of computer-generated graphics.

Augmented virtuality

Augmented virtuality (AV) refers to the merging of real world objects into virtual worlds. As an intermediate case in the virtual continuum of Figure 1, it refers to predominantly virtual spaces, where physical elements, eg physical objects or people, are dynamically integrated into and can interact with the virtual world in real-time.

Virtual reality

Virtual reality (VR) is a technology that allows a user to interact with a purely computer-simulated environment. Most virtual reality environments are primarily visual experiences. The simulated environment can be similar to the real world, for example, simulations for aircraft pilot or combat training, or it can differ significantly from reality, as in computer games. Virtual reality is limited only by imagination.

Reality, augmented reality, augmented virtuality and virtual reality are all positioned on the virtual continuum of Figure 1.

Immersive

The term immersive in this paper refers to the immersion of the user in an image that is either computer-generated virtual reality, mixed reality or reality. In the case of visual technology, the general case for immersion is considered to be when the user's vision is completely filled with the image so that the person feels that they are totally immersed in the displayed world. This may be via a head mounted display, or a large screen projection system or systems in between that make the user feel physically located in an image of a synthetic or real environment even though they are actually located somewhere else.

Interactive

The term interactive in this paper refers to the ability of the user to select objects displayed on the screen environment, manipulate them, interrogate them and acquire information about them. This may be achieved via voice communication, pointing devices, gestures and the use of tracking devices that implement some event or action.

Video display

The term video display refers to an electronic device that is capable of showing a video image generated by an analogue or digital video camera and also an analogue or digital image generated by computer. Video displays include those located in data projectors and other devices.

Haptic device

The term haptic device refers to a physical device that is connected to the display computer directly or indirectly and provides the user with feedback that acts as the sense of touch for the user when the user 'touches' an object in the scene. This may be a simple feedback system as used in computer games or a more intricate device designed to differentiate between for example, soft and hard surfaces, heavy and light objects or hot and cold temperatures.

Orthoscopic

The term orthoscopic refers to having correct vision or producing it. That is, free from optical distortion or designed to correct distorted vision, it literally means to see straight.

TAXONOMY OF VISUALISATION SYSTEMS

Interactive visualisation technology hardware and software advances quickly and is steadily becoming widely available to the public and commercial organisations alike. In general, increased accessibility has reduced the cost of hardware and software technology due to the massive computer games market. Although proprietary systems are still in use, advanced simulation systems can be built from off-the-shelf components and deployed to industry. A number of examples are discussed by Schofield *et al* (2001), Stothard (2001, 2007), Schmid (2003, 2004, 2008) and Unger and Mallet (2007).

The spectrum of technology ranging from high-end proprietary systems through to off-the-shelf game based systems has made entry easier for developers and users alike. However, despite this easy access and relative low start-up cost, a dilemma remains in that capability and system types are not always well understood. Much experience and discussion of system benefit is anecdotal. Sometimes systems that are purchased become under-utilised due to gaps within the culture of the organisation or reticence to accept new methods.

System implementation can be restricted by frugal budgets resulting in compromised solutions where a great effort is placed at the beginning of the decision process to use simulator technology with only a small consideration of the long-term development and support, or integration of the systems into operations or curriculum (in the case of education). A needs analysis is sometimes overlooked as is the cost and sustainability of developing dynamic and meaningful content. Logically, without meaningful and considered content, the systems are limited in what they can deliver and achieve. These systems have the potential to become under-utilised and can stagnate as content and 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 content development cannot be understated.

Occasionally, an organisation presents an opportunity and places its full backing behind systems with impressive results from both a technological and content perspective. Projects such as this are demonstrated by Coal Services Proprietary Ltd (CSPL) of NSW Australia (Stothard, 2007), DMT GmbH & Co KG Germany (Schmid, 2003, 2004, 2008) and National Institute for Occupational Safety and Health (NIOSH) USA (Unger and Mallet, 2007). Organisations such as CSPL have demonstrated a long-term commitment to simulator development and planned implementation in small manageable stages with the technology proven at each stage.

Despite several systems being developed and deployed to industry, the options available to those new to the concept can be confusing. Determining which system has what function and what content can be displayed is also difficult. To assist in alleviating this confusion, in this paper the authors present a taxonomy of mining based mixed reality systems. The taxonomy is based on the early work of Milgram and Kishino (1994). However, it includes modifications to cover subsequent technology advances.

Milgram and Kishino (1994) realised that while virtual environments mimic the properties and laws of the real world and beyond, what is often overlooked is that virtual reality can be associated with other environments. That is, virtual worlds can be augmented with real images and data. For mining operations this presents a powerful tool from both an operations and training perspective where synthetic images derived from predictive data may be combined and overlaid upon real world images and experience.

To date, mining has placed much focus on representing synthetic virtual models of the mine environment. In particular, this approach has proved successful with respect to producing virtual mine training environments (Schofield *et al,* 2001; Stothard, 2001, 2007; Schmid, 2003; Unger and Mallet, 2004; Squelch, 2001; Van Wyk, 2006). Legislated mine training requirements have also driven much simulation development and despite implementations of interactive training simulations described by Unger and Mallet (2007), take up and acceptance by the industry is still very slow. Other industries such as aviation, oil and gas and medicine have embraced the technology (Stothard 2001). The slow acceptance in mining is despite the concept of virtual reality for the mining industry being introduced in the nineties where low cost simulators were discussed by Bise (1997) Denby *et al* (1998) and Squelch (2001), whose simulations represented high-risk environments where the content was mainly synthetic and also contained real-world information such as video clips, photos and web based data.

Virtual continuum

Milgram and Kishino (1994) present their concept of a virtual continuum in a linear form. However, a linear representation may be an over simplification for mining and other high-risk activities where the main issue is often risk and restricted access that impacts on the development, configuration and hence content displayed by computer-based visualisation systems. Levels of risk and the ease of site access to acquire data and images can impact significantly on the transition along the virtual continuum of Figure 1. For example, in the case of a high-risk mining activity, the objective is to remove the risk completely or to minimise it through risk management procedures, which includes performing a risk assessment. Acquiring relevant data and images for a simulation model or visualisation often requires access to the environment that introduces the possibility of a person being injured. The need to remove this risk will prohibit or restrict the collection of data and move the model towards the virtual end of the continuum or impose substitution of another method. Also, the sensitivity of the images or data can be a factor. Mine sites are commercial operations and may wish to maintain confidentiality. Hence an extension of the concept of the virtual continuum of Figure 1 from a mining perspective is necessary to explain the format and factors that impact on computer-based visualisation systems developed for the mining industry. In the case of mining, a ternary diagram is a more suitable representation because one then has the capacity to display all types of content along the virtual continuum of Figure 1. However, we may never actually be able to acquire the data for display in the system. An example ternary diagram is presented in Figure 2 which illustrates a tool where the application and level of virtual reality, mixed reality or indeed reality itself may prevail in specific mining applications. This prevalence will also be affected by the culture within the organisation and the willingness to provide information. Short-termism may result in very basic computer-generated simulators or video clips being implemented whereas a longer term view that aims to build a sustainable capability can result in high resolution mixed reality or virtual reality systems being implemented.

Figure 2 shows how variables extraneous to the system technology affect the development and application of such systems and hence the content that can be displayed. There are other variables for example, such as budget, resistance to change, substitution, etc that can similarly be placed on these axes. However, these will not be discussed here but explored further and in subsequent papers. In Figure 2, risk refers to physical and financial risk involved in placing inexperienced people in hazardous mine environments. This is an occupational health and safety issue that would apply on most mine sites who wish to keep risk exposure, for everyone who visits the site, to an absolute minimum. In Figure 2, the term 'prohibitive' means that actually gaining safe access to the site to be modelled is difficult and in many cases highly dangerous for the inexperienced. The term 'difficult' refers to situations where accessing video data is more difficult or expensive than actually exposing the user to a reality model of the real environment – particularly when the risk to personnel is controllable. The boundaries of the areas 'controllable', 'moderate' and 'uncontrollable' are fuzzy and not necessarily neatly delineated and, hence, are shown as broken lines. OEM means original equipment manufacturer.

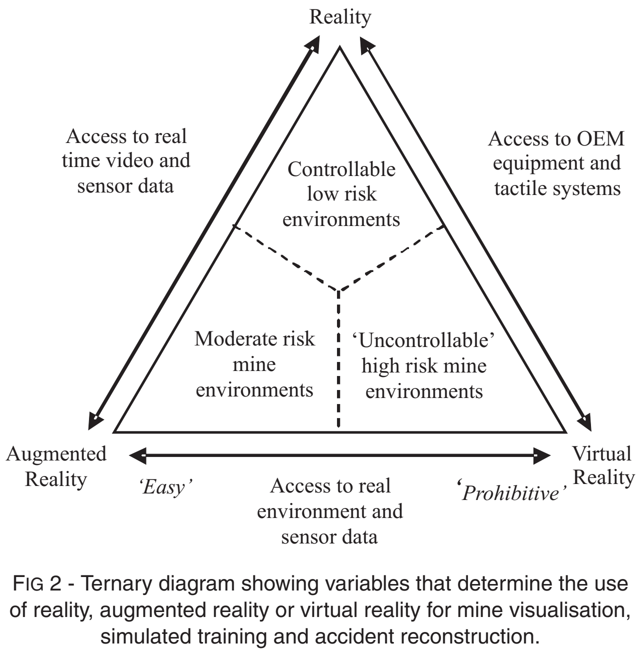

FIG 2 - Ternary diagram showing variables that determine the use of reality, augmented reality or virtual reality for mine visualisation, simulated training and accident reconstruction.

Where risks are fully controllable and the variable of cost is not an issue, tactile reality training environments may prevail. However, due to the fixed nature of reality, these can be very expensive and difficult to modify once established. Mines Rescue

Proprietary Ltd (MRPL), as subsidiary of CSPL has very successfully followed this route for certain training objectives and also combined this approach with computer-based systems. Where tactile systems have been implemented they can be used in conjunction with mixed reality systems and present the user with a real-world experience such as donning self escape equipment and working at heights where the physical experience of wearing the equipment and understanding its physical operation is paramount. The virtual environment scenarios are then used to reinforce the experience gained in tactile simulations (Stothard, 2005).

Relating this to the proposed taxonomy of interactive visual environments, Figure 2 shows how systems and the content that they display may move around and evolve to fit niche criteria and possibly follow a process of natural selection driven by forces external to the continuum. For example, uncontrollable high-risk environments when used for training purposes may manifest as purely virtual reality environments where models are built as artist's representations of the real environment drawn from expert experience. Whereas, on-site moderate risk operational training may manifest as augmented reality or mixed reality.

In an attempt to make a classification of systems and what they can display, Milgram and Kishino (1994) present several classes of hybrid display environments as summarised below. As part of the taxonomy development presented in this paper, the authors have extended these classes to include evolution of visualisation systems and content that can be displayed. The classification below is taken directly from Milgram and Kishino (1994):

- Class 1 – Monitor based (non-immersive) video displays – ie 'window-on-the-world' (WoW) displays – upon which computer generated images are electronically or digitally overlaid. Although the technology for accomplishing such combinations has been around for some time, most notably by means of chroma-keying, practical considerations compel us to be interested particularly in systems in which this is done stereoscopically.
- Class 2 – Video displays as in Class 1, but using immersive head-mounted displays (HMDs), rather than WoW monitors.
- Class 3 – HMDs equipped with a see-through capability, with which computer generated graphics can be optically superimposed, using half-silvered mirrors, onto directly viewed real-world scenes.
- Class 4 – Same as Class 3, but using video, rather than optical, viewing of the 'outside' world. The difference between Classes 2 and 4 is that with 4 the displayed world should correspond orthoscopically with the immediate outside real world, thereby creating a 'video see-through' system, analogous with the optical see-through of option 3.
- Class 5 – Completely graphic display environments, completely immersive, partially immersive or otherwise, to which video 'reality' is added.
- Class 6 – Completely graphic but partially immersive environments (eg large screen displays) in which real physical objects in the user's environment play a role in (or interfere with) the computer generated scene, such as in reaching in and 'grabbing' something with one's own hand.

The classification was published in 1994 and since then the application of head mounted displays has not been as prominent or popular as it may have been at that time. Other technologies have emerged and become very popular such as mobile devices and phones. Domes, CAVE systems and Visionariums have also been developed and deployed on numerous sites and new ideas emerged. To cater for these and the content that they may display the classes have been extended and are shown in Table 1. Class 6, an existing class, has haptic devices added. The primary additions are Classes 7 through to Class 10:

- Class 7 – Large full surround screen(s), completely graphic environments that are fully immersive and use real physical objects or haptic devices to play a role in the computer generated scene. Examples of these are CAVE and Visionarium systems and in some cases Domes. These systems are large spaces intended for individual or group experience.
- Class 8 – Devices with a capability to see through to the real world and show computer generated graphics simultaneously (analogous to a 'see through' PC sized screen).
- Class 9 – Hand-held mobile devices with the capability to show video of real world and computer generated graphics simultaneously. Examples of this technology are a number of mobile phones and experiments have been performed by Henrysson, Marshall and Billinghurst (2007) to explore the concept of mixed reality graphics on mobile devices.
- Class 10 – True 3D holographic or hologrammatic representations that mix reality with the real world. Interactive holograms are still in development and their potential use will be covered in subsequent papers.

The additional classes have arisen as technology has improved and have become applicable to industry since the original taxonomy was conceived; noticeably, large screen virtual environments and the ability of physical objects to interact with the environment (Stothard, Mitra and Kovalev, 2008). Also, hand-held devices have been added whereas the head mounted displays have become less 'weighted' in the classification. In the case of large screen displays, this may be the result of improved clustering of graphics machines and the subsequent high quality edge blending of images to form one almost seamless image or the ability to display a single high-definition wide screen image. This allows large screen virtual environments to provide group experiences of the mining environment and also high resolution details to be included in the virtual environments (Stothard, 2007). Hand-held devices have also become popular and these devices often have video and easy networking capability making them potentially useful for onsite information access. It should be noted that class 9 devices have the capacity to be operated within other classes particularly Class 1, 5, 6, 7 and 10 and will equally have application along the full spectrum of the virtual continuum. A schematic representation of these systems is shown in Figure 3.

The virtual continuum shows that real environments, mixed reality environments and virtual environments are located on the continuum. However, in the case of mining, how virtual environments evolve and what information is included in them may not necessarily lend itself to a one-dimensional linear representation. Development of mixed reality systems may be controlled by forces extraneous to the continuum. Risk relating to the collection of images and data are an example of one of these forces. Where risk is controllable, reality may prevail. Where risk is 'intermediate' mixed or augmented reality may prevail. Where risk is uncontrollable virtual reality may prevail.

Taxonomy of content

Simply considering visualisation technology and the relative number of objects and pixels that can be displayed is insufficient insight for making design decisions about which mixed reality displays should be utilised (Milgram and Kishino, 1994). The authors concur with this comment based on their experiences worldwide in gaining acceptance for the use of mixed reality and virtual reality systems into the mining industry. One example is the system developed by UNSW and CSPL for the New South Wales (NSW) coal industry in Australia (Stothard, 2007). During the development of this simulator, a major turning point and lever was the development of high resolution virtual mine

TABLE 1

Classification of mixed reality display systems (modified after Milgram and Kishono, 1994).

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

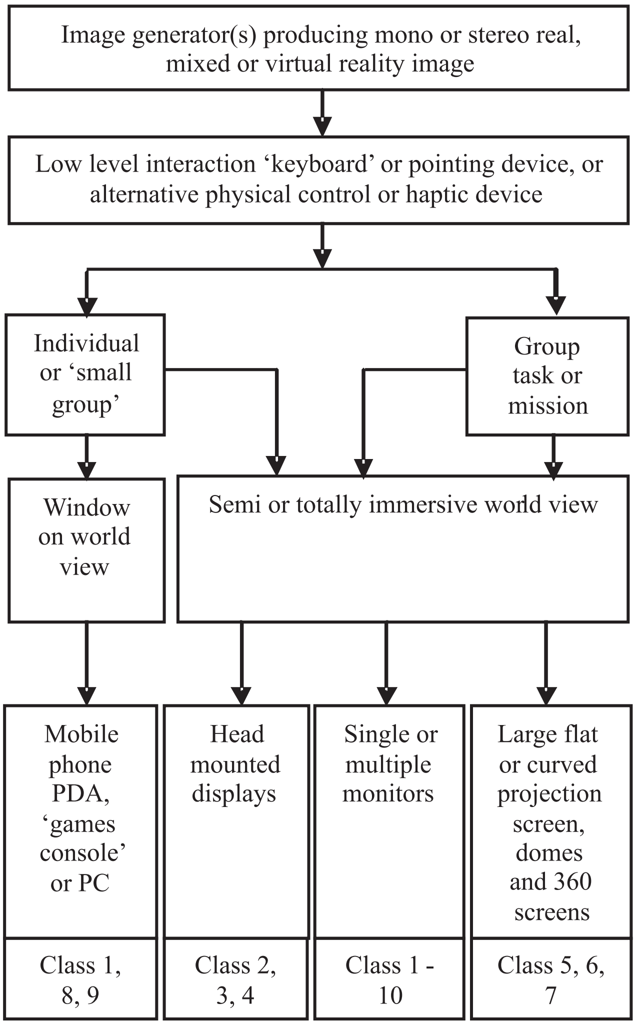

FIG 3 - Example hardware visualisation system configurations available to the mining industry.

environments containing rich interactive content displayed on large screen environments. Content was closely derived from core competency requisites for mine workers. In the South African context, an additional barrier to acceptance is the sometimes low schooling levels of the mining workforce and hence the need for a more graphical approach to material delivery. A South African system that uses a graphical approach for interaction is described by Squelch (2001). Another example is the development of interactive maintenance and repair scenarios of major underground mining equipment for the German hard coal mining industry. Due to the availability of WIFI access underground the content recall directly at the repair site appears possible. ATEX-proof handheld PCs were developed instead of tablet PCs. Despite sophisticated interactive knowledge representations the system became unused because of the graphical limitations of the Handheld PC, which was only capable of showing video (Schmid, 2008).

Another highly important part of the evolution of interactive visualisations for the mining industry is the development of meaningful and relevant content. Fundamentally, the selection, development and delivery of meaningful content is derived from a needs analysis performed by industry experts or an appraisal of the real-time information that must be interfaced to an operator in mining operations via simulations or via a virtual or augmented computer-generated environments.

Mixed reality content realism

Two dimensions affecting realism in mixed reality displays are considered by Milgram and Kishino (1994). These are image quality and immersion or presence within the display. Image quality realism was also identified as a major issue. Industry expectations about the 'look' and 'feel' of the simulations are such that a pre-conceived perception of what is acceptable and useable in terms of image quality impacts heavily. That is, a virtual mine should 'look' and 'feel' like a real mine to overcome the 'our mine doesn't look like that' mentality (Stothard, 2007). In the case of mine training simulators for group based competency exercises, the image resolution plays a major part, particularly where small and subtle details need to be demonstrated. In many forms of underground mine training, the quality of the images are considered highly important as small detail is often of interest as is the need to suspend disbelief. In the case of a gas outburst for example, some of the geological indicators are so subtle that only a trained geologist would 'easily' recognise them. For day-to-day operators to gain experience and recognise such subtle indicators, the resolution must be high and truly representative so that the untrained can learn from the simulations.

Further dimensions relating to realism are immersion and presence, again in the case of the mining industry, the level of immersion for demonstrating spatial awareness and the relationships of mine infrastructure and operations are considered important. The sense of presence in the environment is also a high priority as the aim is to provide environments that replicate the work environment very closely (Stothard, Mitra and Kovalev, 2008; Tromp and Schofield, 2004). In many underground mining scenarios, the 'swing' of Figure 2 is toward purely virtual environments due to limited and consistent access into hazardous zones and the dynamic nature of the coal mine environment development process.

Elements of reproduction fidelity are shown described by Milgram and Kishino (1994) and shown in Figure 4 where the low fidelity anchors one end of the dimension and high fidelity images anchor the other. The diagram shows video resolution and high definition television above the arrowed-line and the increasing resolution of synthetic images below the arrowed-line. The reproduction fidelity relates to the non-direct viewing of objects. That is, everything shown on the screen is either computer-generated or has passed through some electronic equipment.

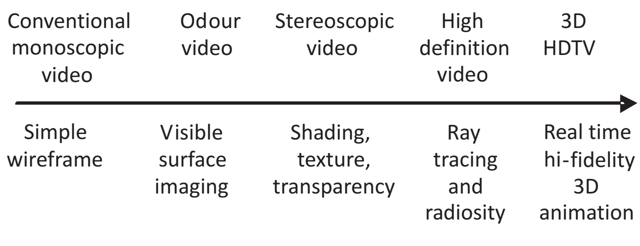

FIG 4 - Reproduction fidelity dimension (after Milgram and Kishino, 1994).

Reproduction fidelity, therefore, relates to the ability of the synthesising equipment to reproduce the images relative to the way it would appear in reality. The ultimate would be to develop systems that appear on the right hand side of Figure 4 so that real world and synthetic images are indistinguishable, however, there are many factors that need to be managed to achieve this – a discussion of these factors will be undertaken in subsequent papers in this series.

In cases below the line of Figure 4 where a high fidelity, high resolution animation can be used, the experience of the viewer can be completely known as the environment is synthetic.

Whereas in the case of mixed reality, the inclusion of real-time video or in fact pre-recorded video of an environment may present an opportunity for undesirable or unintentional information to be included in the image. For competency, or development of best practice this would be undesirable. In this case, the human observer of the images would be unable to distinguish between the hardware generated images generated and displayed by the technology to the right and above the line and the 3D models displayed by software and technology below the line. The only difference would be a controlled or pseudo-controlled image. Conversely, when performing an evaluation of a mining task, real time video with uncontrollable variables may be more beneficial to the user towards the development of knowledge and experience.

Interaction metaphor

The second dimension is interaction in immersive mixed reality or virtual environments and is a key concept and prerequisite for successful utilisation of the content displayed by the systems. One of the objectives of developing simulations – particularly for education or experimental purposes – is to provide an experience for the user that encourages them to explore the environment and gain knowledge and experience by 'doing' and problem solving as opposed to potentially passive learning experienced in traditional lectures and tutorials (Adams, 2001).

Interaction devices provide a synthetic medium for interaction between the user and the mixed reality environments. There are many variants of point and click devices and navigation devices; however, the interaction metaphor relating to the interactive content presented to the user is equally if not more important. Examples of interaction devices are mouse pointing devices, keyboards, inertia cubes and data gloves. More sophisticated interaction methods that include voice recognition, gesture recognition, haptic systems and infrared tracking and location devices are also available. Interaction can also be based on technology such as mobile phones and PDAs that operate within the environment, as described earlier.

In Figure 5 an interaction metaphor is presented and shows how the interaction metaphor changes from static or passive experience with no interaction through to bi-directional multi-modal interaction where the interaction paradigm is group based team work.

An issue with mine sites can be that site access and hence the reality based apprentice-mentor metaphor that would occur under the reality subsection is very difficult to accommodate due to risk issues on the sites and also logistical issues. Alternatives are required and as the abscissa of Figure 5 is traversed it is seen that the material can be combined together to develop potentially more meaningful interaction as content richness increases. Content can be displayed at varying levels of complexity on the devices indicated in Table 1 and in Figure 3. In the middle there is a mixture of real and virtual components as described by the virtual continuum of Figure 1. The metaphors for the experiences gained by the users also increase in number with mixed reality and virtual reality providing a combination of techniques that may be applied to deliver the required outcomes from users interacting with the systems. The level of interaction required to engage with the content also increases towards the upper right of Figure 5, where automated interaction would be via an intelligent agent or avatar that can equally interact with the human participants and the mixed reality or virtual environment. Hand-held Class 9 devices operating with Class 5, 6, or 7 devices could act as an intelligent agent. Potentially, the experience gained with the Class 9 devices could be transferred directly to the real mine site. The upper right hand corner can also provide interaction metaphors for environments where the conditions for access to sites are prohibitive, as indicated in Figure 2.

The interaction metaphor may also be one of interaction with intelligent graphical search engines where metadata is applied to imagery and when a user 'points' or gestures towards an object in the simulation, the system through previous knowledge and experience with the user 'knows' what object is of interest and automatically searches a database of information pertinent to the object of interest. The user can then interrogate that information graphically. This information would occur towards the upper levels of the mixed reality and virtual reality sections.

Presence metaphor

The Extent of Presence Metaphor presented by Milgram and Kishino (1994) is shown in Figure 6. The metaphor is modified slightly to incorporate the 360 degree environments that are now readily available to industry. The term presence is described by Whitmer, Gerome and Singer (2005) as:

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

Milgram and Kishino (1994) recognise that most of the systems in their classification have the ability to provide a strong presence metaphor. The authors concur and extend this comment to Class 7 systems and to a lesser extent 8 and 9. Mine workers exposed to Class 6 mixed reality displays, that included highly immersive environments designed for underground mine visualisation and training were found to have a high sense of presence (Stothard, Mitra and Kovalev, 2008) in the virtual environment. However, presence in semi-immersive and fully immersive environments may relate to image size and reproduction fidelity and further study in relation to virtual mine environments is required.

The metaphor of Figure 6 suggests anecdotally that as the system becomes more immersive and the image becomes 'life size', the extent of presence increases. From a pedagogical aspect where the educational method is apprentice and mentor, the need for images that accurately portray the mine environments is important. This need for a high sense of presence is twofold in the form of a combination of the requirement to provide accurate information to the apprentice and the need to immerse the mentor in an environment where the mentor 'believes' the environment and can interact with small and large detail resulting from a high reproduction fidelity. That is, the mentor believes the environment and hence the apprentice will (hopefully) learn from experiencing the 'believable' environment with the mentor.

The extent of presence metaphor for the Class 7, 360 degree system of Figure 6 appears to be very high and may actually be quite advanced due to the users experiencing almost complete immersion when placed in the environment. Once the interaction metaphor is implemented, the level of immersion has the potential for presence to be complete as the users becomes totally immersed in the images and feel present in the scenario. The sense of presence may also be increased due to the ability of the user to implement lateral head movements and experience local motion parallax resulting from viewing panoramic images. However, at this stage, this is purely anecdote and is being formally studied to investigate other factors that apply. Early experience does however suggest that the Class 7 systems do allow the user to naturally look around a scene and navigate the scene in real time and the users are effectively inside the virtual mine environment.

	Reality (Mine site)	Digital Reality	Mixed Reality	Virtual Reality
	Apprentice-mentor metaphor.	'Traditional' classroom-metaphor.	Combined virtual apprentice-mentor and real life metaphor.	Combined virtual apprentice mentor, 'traditional' classroom and 'real' life metaphor.
Bi-directional multi modal information and group dynamics	Direct group based team work on real equipment.	Site remote group based team work via interactive video conferencing and internet activities equipment.	Direct and remote group experiences via computer generated and real environments containing Human or Virtual Agents and Avatars sharing the same virtual mine as humans.	Direct group experiences via purely computer generated environments containing Virtual Agents and Avatars sharing the same virtual mine as humans.
Bidirectional information	Direct experience, eg from within work site or inside a vehicle guided tour performing a task or collecting data in real time.	Site remote experience via two way interactive real time interactive videos, sounds, photos and web based media.	Mixture of direct real and virtual mine site data remotely experienced via 'pre-recorded' CAD drawings, videos, photos and sounds placed in computer generated models and fly throughs enhanced by human 'mentor'.	Direct group experiences via purely computer generated environments. Lead by human facilitator. Real time data controls the model parameters.
Unidirectional information	Direct experience via live television broadcast.	Site remote experience via interactive pre-recorded or passive video and web based media.	Remote experience via Mine site fly throughs and animated models, interactive pre-recorded videos and web based media enhanced by human 'mentor'.	Direct experience via interactive 3D models, computer generated models, fly throughs and pre-recorded 3D model video.
Static Non-interactive	Mine site remotely experienced by non-electronic techniques, eg viewing platform.	Site remote experience via pre-written text, photos, PowerPoint slides or passive video presentation.	Mixture of real and virtual mine site images remotely experienced via pre-recorded, videos, photos and sounds placed in computer generated models and fly throughs.	Pre-recorded technical procedures combined with computer generated models, fly throughs and pre-calculated data.

Real → **Virtual**

FIG 5 - Interaction metaphor.

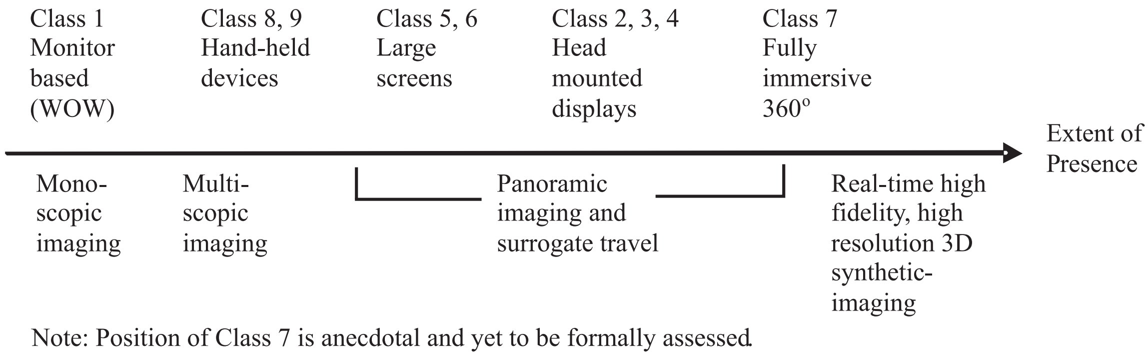

FIG 6 - Extent of presence metaphor (modified after Milgram and Kishino, 1994).

CONCLUSIONS

Mining is a high technology industry that embraces technology and strives to improve safety. Computer-based visualisation technology and content has the potential to further improve safety and production.

Computer-based visualisation systems are affordable and established technologies. However, the mining industry has been cautious about embracing this technology despite it being in existence for decades. A contributing factor may be that the full capability of the technology is difficult for the uninitiated to ascertain and fully understand due to the plethora of technology available and also the vast amount of data and information that can potentially be displayed on the various systems.

Computer-based visualisation systems were classified through a generic taxonomy developed in the mid-nineties. Although this classification is an academic exercise, it did present an overview of what these systems can achieve. Some of the terms are confusing and to assist in understanding the terminology of common terms have been defined in this paper.

Since the original taxonomy was presented, there have been advances in technologies that can make it difficult for the uninitiated to determine what technology performs which action and what content is available. Hence, a modification to the taxonomy was required and this has been developed by the authors. The result is that several more classes have been added to the taxonomy that encompasses new and innovative technologies.

In addition to the taxonomy of visualisation systems, a broad taxonomy of content has been also been presented that shows how the various content drawn from the virtual continuum can potentially be brought together to provide rich interactive content for use in mining applications. The development of interactive content draws upon the concept of the virtual continuum however; the virtual continuum is a linear mechanism and for mining applications this was considered insufficient for the development of mining content as factors extraneous to the computer-based systems dictate the position that mining simulations take on the continuum. To show the impact of these external influences on content development and system choice, a ternary diagram was introduced that shows where reality, mixed reality or virtual reality may dominate.

Factors such as image realism and fidelity are also considered to be highly important due to the high standards that industry sets for any equipment it uses.

High quality interaction is also considered important and several interaction metaphors presented. The preferred interaction metaphor would be one of multimodal, bi-directional interaction with rich content drawn from a blend of reality, mixed reality and virtual environments. Less favourable content would be static in nature.

The level of immersion in computer-based systems is also an important factor and increased immersion appears to be related to increased presence in virtual environments. However, this is subjective and requires further study. Although anecdotally, it would appear that large full surround screens that show a one-to-one scale image of the mine environment and which have an interaction device for the user to interact with the environment, may provide a high level of presence suitable for learning about and assessing the mine environment.

Mixed reality virtual environments for the mining industry have many possible configurations and can potentially show any real, mixed-reality, or virtual reality content to a user. Developing meaningful content in the future requires the continued support from industry to develop a knowledge-base and sustainable computer-based visualisation systems that will benefit the wider mining community.

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Appendix B: Example Module Brochures

Appendix C: Business Model

Executive Summary

The University of NSW's School of Mining Engineering has developed the Know-How to create high-quality customised Virtual Reality Training Simulations and Visualisations that improve safety training for occupations in unsafe situations and environments.

To establish the effectiveness of the Know-How the School has formed the VRGroup to research, develop, implement and test Virtual Reality (VR) Training Simulations and Visualisations.

The VRGroup has proven the effectiveness of the Know-How by creating eight underground mining training modules and a growing digital asset library. These are now part of the VRGroup's Intellectual Property and can be licensed to future clients.

The VRGroup's Simulations enable organisations to train their staff to recognise hazards, observe possible consequences and take corrective action in a safe, risk-free environment carefully designed to produce better learning outcomes than conventional training methods.

These Simulations have been successfully implemented and tested in very demanding conditions, indicating the potential for the VRGroup to become a commercial business.

The initial service offering targets the training organisations that service the mining industry. This is an area in which the VRGroup has already established itself, with products already in service and future orders in hand.

A critical success factor for the VRGroup is the ability to access essential information about workplace environments and equipment. This access can only be gained through the co-operation of industry, and is difficult to get without the support of UNSW's School of Mining Engineering.

Until recently the technology used to create and display VR content has been unable to deliver quality high enough to satisfy industry. With the support and resources of the University of NSW the VRGroup is at the forefront of emerging technologies, using the latest 3D software applications to provide high-quality Simulations that provide the trainee with a realistic experience and adds significant value to the training process.

The VRGroup's revenues will be generated through:

- Custom Modules: Customised training modules designed to faithfully represent a specific environment and training situation, created with new material supplied by the client. Where possible the VRGroup will retain the rights to the material it develops so that it can be re-used to create Generic Modules.
- Generic Modules: Combining material previously produced for other projects with assets from its growing digital library the VRGroup will produce Generic Training modules (with some customisation) at a much lower cost than fully customised modules.
- Licensing Models: Licenses will be negotiated for both Custom and Generic training modules, on an 'annual' or 'per-user' basis.

An initial analysis of the financial viability of this venture shows outstanding results and promise. The market for Advanced Training Simulations such as those offered by the VRGroup is significant.

Two options for incorporating the Know-How into a commercial venture are:

- As a standalone business: The financial projections included with this plan assumes that the VRGroup will become a standalone business with no external support from a parent company. This option requires a very senior manager (Managing Director) to manage the business full time.

  Detailed financial projections are included in the appendices of this plan. The following is a summary of those projections (for a standalone business):

- As part of a larger business: If the VRGroup were to become a Division of a larger company its costs would be lower - it would not require a full time Managing Director, for example, and would be able to share some of its expenses, such as occupancy and other costs, with its parent.

  As a Division of a larger company the VRGroup would also benefit from the relationships its parent already has with key industry groups, increasing its speed to market and lowering risk.

Introduction

The objective of this plan is to provide existing and potential stakeholders with an understanding of the potential for the VRGroup to operate as a standalone business, as part of a joint venture or as a wholly owned subsidiary of a larger organisation, by providing an overview of the:

- Products and services offered by the VRGroup,
- Market in which the VRGroup operates,
- Critical Success Factors for the VRGroup,
- Resources required to operate the VRGroup, and
- Financial indicators

The objective of the VRGroup, as a commercial entity, would be to generate sufficient profit to finance future growth and to provide the resources needed to achieve the other objectives of the company and its shareholders.

Critical Success Factors

The factors critical to the success of the VRGroup include:

1. Information Gathering:

   The ability to identify the training need and interpret the need to create a tailored solution that provides a better training outcome than conventional methods,

   The ability to quickly and efficiently gather essential information - knowing what information to collect, how the information is collected and documented, and

   Understanding of how the information is used to create the final VR Training Simulation.

2. Access to the Mining industry

   Management support of the VRGroup and its Simulation models is essential in providing access to the people and resources required to create Training Simulations,

   Managers are sceptical about new technology and its usefulness in providing better training outcomes. Until recently VR technologies haven't met the expectations of industry, but now, with the introduction of the highly detailed models and more accurate simulations produced by the VRGroup, managers are starting to recognise the value of VR Training.

3. The UNSW School of Mining Engineering

   The credibility provided to the VRGroup by the School and individuals such as Professor Jim Galvin, Professor Bruce Hebblewhite and Dr Phillip Stothard helps to assure managers of the integrity and value of the VR Training model.

Feedback from Users

Users provide feedback that helps to create more accurate simulations.

Positive support helps to influence management, while negative feedback helps refine the model.

4. Immersive Experience

   Ability to create and deliver an immersive and interactive experience. This requires access to 3D delivery technology (a significant investment in a visualisation system that suits the training organisation's needs)

   Accuracy of models, resolution (how it looks) and fidelity (how it behaves - how well it represents the real environment)

   Ability to deliver needed content quickly and at a reasonable price.

5. Digital Assets

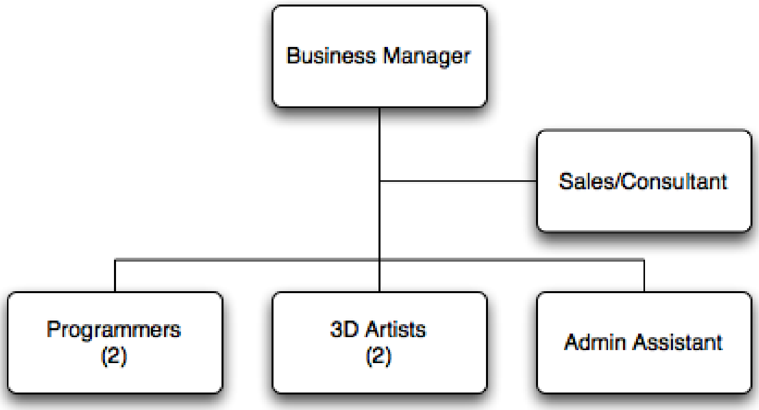
   A growing asset database of videos, digital photos, CAD drawings and 3D model library. As the library grows the individual assets will be re-used, significantly reducing the cost of sourcing information and creating models for each new implementation.

Company Structure

The VRGroup is a relatively small organisation that could either be operated as a standalone business or as part of a much larger organisation.

Organisation Chart

The Organisation Chart reflects the nature of the business - most of the human resources are employed in



the actual production of VR content:

1. Business Manager -

   Key responsibilities - include running the 'business' side of the organisation, including financial aspects, and managing the production team (Programmers and Artists)

   Required background and skills (depending on the business structure) -

- If the VRGroup operates as a standalone business - the Business Manager will effectively be the Managing Director and will need to be experienced in managing a content creation business at a high level, with a detailed understanding of the production process and the critical success factors involved in profitably running a small enterprise,
- If the VRGroup operates as part of a larger organisation - the Business Manager will be the 'divisional manager' (possibly managing the VRGroup as part of a portfolio) and will need to manage the VRGroup to work closely with other parts of the organisation.

2. Sales/Consultant -

Key responsibilities - include selling the VRGroup's services to companies and training providers and liaising with those organisations to collect the information needed to build the VR simulations

Required background and skills - this essential role requires relationships with key stakeholders in mining and training companies, the ability to establishing trust and manage projects. The ability to interpret training processes and to adapt (and improve) those processes for virtual simulations.

3. Programmers and 3D Artists

Key responsibilities - converting drawings, photos and videos into photo-realistic virtual environments with realistic animations and training content.

Required background and skills - qualifications and experience in programming and illustrating 3D models.

Products and Services

The VRGroup produces customised virtual reality training simulations for organisations that need to to train employees to work in hazardous environments or deal with dangerous situations.

The VRGroup's highly accurate photo-realistic 3-Dimensional representations enable training organisations to prepare trainees much more effectively for work in a hazardous environment.

The simulations include highly detailed environments, the equipment used, and any hazards that may be encountered. Complex atmospheric effects, physics simulations and animated human characters are placed within each simulation.

Training situations are incorporated into each model, including interactive choices that the trainee will be presented with. Trainees interact with the simulation through a touch screen and joystick interface. The choices they make are tracked, and at the conclusion of the simulation a record of their results is saved by the operator for assessment.

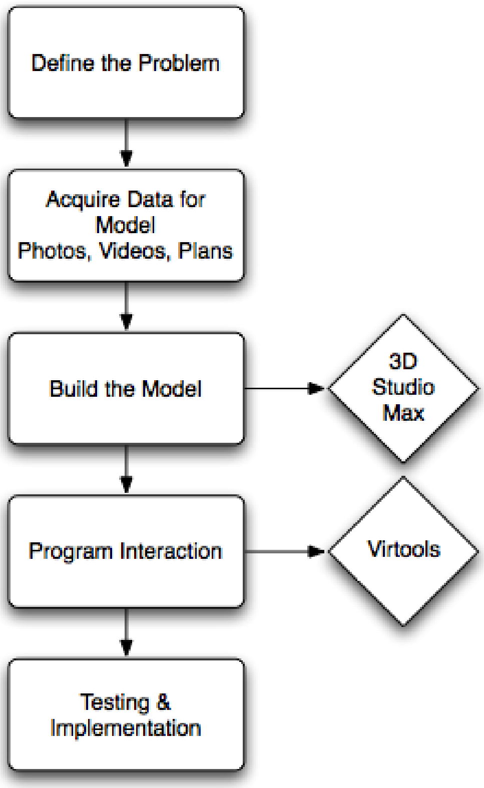
Licensing Options

Model 1 - Creation of fully customised VR Training Solutions to meet the needs of specific clients and training situations.

Model 2 - Modification of existing models with a small amount of customisation.

Model 3 - License existing (generic) models 'as is' without modifications

Training Simulation Production Process



Benefits of Virtual Reality-Based Training

The benefits of virtual reality simulations include:

Cost savings - expensive equipment, such as multi-million dollar mining equipment, doesn't need to be taken out of service,

Evaluation of equipment - using accurate 3D models companies are evaluate the compatibility of various pieces of equipment, checking size and fit, for example,

Evaluation of disparate data sets so they can make informed decisions

Training needs analysis - some companies provide lots of training, but it is not all competency-based and often doesn't provide satisfactory training outcomes

Benefits for Training Organisations

The VRGroup's VR Training Simulations provide training organisations with a number of important benefits:

Changeable Environment - using computer-generated environments enables training operators to quickly and easily change environments and training situations,

Training Venues - a single training venue can represent any mine, reducing the cost of setting up separate environments for each training client, Multiple Trainees - using the VRGroup's simulators trainers can train multiple people simultaneously, with every trainee getting the same high-quality training and experience,

Standardised Experience - each trainee receives an identical experience based on the competencies required

Regulated Training Standards - can be enforced, with consistent delivery over time,

Educational Value - can be assessed to determine the value, validity and efficacy of the training content,

Interactive Experience - for people to progress through the simulation they have to participate - they can't passively sit through (as might with video- or lecture-based training)

Trainee Evaluation - operators can track an individual's performance over time, and look back if needed. If, for example, an individual took risk leading to accident, the operator could check to see if they were trained in a procedure,

Spatial Perception - 3D provides spatial awareness, enabling trainees to 'feel' and experience the entire environment, not just how to use a tool or a switch.

Proven Success

The VRGroup has already proven its VR training model with successful implementations of underground mining simulations for Coal Services in NSW.

After an initial trial the Coal Services board has ordered a total of 8 VR training modules at an average cost of $50,000 each.

The mining industry in Australia continues to experienced significant growth. Employee numbers across the industry have grown from less than 80,000 in 2000 to over 140,000 in 2007.

Market Analysis

To maintain their important role within the industries they serve specialised training organisations need to find faster, more efficient ways to train new employees. This has created an urgent need to develop new training methods that are:

Highly specialised,

More effective, and

More reliable.

This provides opportunities for the VRGroup, which uses the latest virtual reality technologies to develop training simulations to:

Customise environments and training situations for almost any working environment,

Tailor training messages and required responses and interaction to ensure the most effective training outcomes, and

Provide a consistent training message over time for a large number of groups and individual trainees.

Trends in Training

Current and emerging trends in training that have implications for the VRGroup include:

Vocational training - a growing trend towards competency-based vocational training.

Quality of training - is becoming increasingly important,

A smaller workforce - employees are more highly skilled, able to multi-task,

Expectations from sponsors of training and trainees are higher - as a result training standards are higher,

Greater investment in training - companies are placing high importance on employees working productively from Day 1.

Equipment - in the workplace is becoming more complicated and expensive. Formerly low-tech environments - such as underground coal mines - are now full of high-tech equipment that requires specialised competencies

Training technology - as the complexity of workplaces and equipment increases trainers are becoming increasingly reliant on multi-media technology such as PowerPoint presentations and video to communicated complex training messages.

In the short-and medium term the impact of globalisation has led to fewer mining companies - but much larger international companies.

Competitors

The VRGroup's competitors can be divided into three groups:

Research Groups - including other universities. The VRGroup, through its links to UNSW, has the opportunity to collaborate with some of these groups.

Training Organisations - currently use conventional technologies to produce vocational training. Although currently competing for training dollars these organisations may become customers or distributors of the VRGroup's products.

VR Suppliers - adapting Virtual Reality technologies to training applications. These companies provide a range of technologies and VR training solutions. Some, such as 5DT and Immersive Technologies are both competitors (for simulation training) and suppliers for the software and hardware used by the VRGroup.

Many of these competitors are also suppliers and providers of VR, and could potentially be collaborators in the future.

Competitor	Details
Research Groups	University of Queensland http://mining.minmet.uq.edu.au IVEC (WA) http://www.ivec.org RESA (SA) http://www.unisa.edu.au/resdegrees/news/highlights.asp
Training Organisations	Mines Rescue Service NSW http://www.minemergency.com.au RIISC - Resources & Infrastructure Industry Skills Council http://www.riisc.com.au/Coal-Resources/default.aspx ITAB (MineSafe) (NSW) http://www.minesafe.org/home/index.html TAFE http://www.tafensw.edu.au Training Minerals Industry Skills Centre (Qld) http://www.miskillscentre.com.au
VR Suppliers	5DT (working closely with Joy) http://www.mining.5dt.net/miningintro.html Immersive Technologies (aligned to equipment suppliers including CAT) http://www.immersivetechnologies.com SYDAC http://www.sydac.com.au VR Solutions http://www.vrs.com.au THALES http://www.thalesonline.com/

Marketing

Entry Strategy

The most significant initial market opportunity for the VRGroup is the production of content for training simulations for underground mining. This is an area in which the VRGroup has already established itself, with products in service and future orders in hand.

If the orders were transferred to the newly commercialised VRGroup entity it would provide significant start-up cash flow and potential to grow the business.

This would only be the first channel, with opportunities emerging in:

Defence,

Fire Services

Chemical, and

Transport industries

Value Proposition

The VRGroup's value proposition is 'high quality training content delivered in a consistent, effective and quantifiable manner'

It articulates this value as 'improving the understanding of the mine environment to people who are going to work in that environment, by providing experience to people before they ever go into the mine environment'.

Trainees are equipped to solve problems, able to hit the ground running, are better prepared, have increased safety awareness and are more productive following VR Simulation training.

Barriers to entry

The ability to provide such a high-quality immersive training experience is currently very unique. It requires a significant investment in computers, software and people to be able to match the VRGroup's ability to produce high quality content and training outcomes.

Technically - it would be very difficult for a start-up to match the VRGroup's ability to create high quality content.

Access - even if a competitor were able to match the technical competency of the VRgroup it is unlikely that it would gain sufficient access (without the support of the UNSW) to be able to create the highly customised environments required by training providers.

Standards - there is no standard for content and interaction. Each training module is developed in isolation and can't be used on other systems.

Switching costs - the initial investment required to from the company or training provider to be able to display the VRGroup's training content is significant (many hundreds of thousands of dollars). The ability for a new entrant to be able to display their own content on this equipment is limited, limiting the ability for training organisations to switch to a new content provider.

Customers

The arena in which the VRGroup currently operates is the mining training industry in Australia. The managers of the VRGroup believe there is a very real opportunity to market its products overseas, with China offering significant opportunities for expansion.

Potential customers include:

Mining companies- multinationals down to individual operators,

Coal standards boards and Government regulatory bodies

Training service providers

Individual miners

Other industries/vocations

Currently the most profitable target market segments appear to be:

- NSW Minerals Council, and
- Large mining companies

Additional Revenue Opportunities

Beyond the current focus on mining education in specialised training facilities opportunities exist for expansion into other areas, such as:

- Deployment of the VRGroup's content as web-based software, providing greater access to remote areas,
- Expansion beyond training to VR logistics and planning, simulating risks and difficulties in moving around environment.

Additional revenues could also be generated through:

- Service contracts - on hardware and software, and
- Upgrades to software

Competitive Advantage

The VRGroup maintains several key advantages over its competition:

- Relationships with Industry - the VRGroup through the UNSW School of Mining Engineering has long-standing relationships with key industry bodies including the NSW Joint Coal Board, which has funded much of the research into VR Training Simulations.
- Access - these relationships provide access to information, people and sites that would otherwise be unavailable.
- Relationship with the UNSW - a continuing relationship with the School will provide ongoing access to the latest research and provide a constant 'first mover advantage' as research is converted into commercial products and services.
- Quality of training - the ability to work closely with the peak industry training body, mine management and staff, combined with the professional experience of the VRGroup's managers provides a unique understanding of the training needs of mine operators and employees. This translates very effectively into a much better educational experience and training outcomes for trainees.
- Quality of content - the VRGroup uses the latest Virtual Reality modelling software and display hardware to produce a photo-quality 3-Dimensional virtual environment. This provides an 'immersive' training experience that provides trainees with a genuine appreciation of the risks and environment they will find in the workplace.
- Asset library - as the VRGroup continues to create customised training models for its clients it also is also building a digital asset library of photos, drawings and 3d models that it will be able to re-use on future projects. Over time this will significantly reduce the cost and time required to produce new modules, providing a further competitive advantage.

Value Drivers

Macro value drivers for VR Simulation Training are:

- Technology - increased level of immersion and interaction brings increase in technology complexity and cost.

Delivery systems - can range from PDA to immersive 3D environment depending on required level of immersion and the type of information being delivered.

Management - for data collection, creation of training scenarios and content production. People at high levels are difficult to find - they need productive relationships with key stakeholders, reputation and skills, and vision. They need to be able to add a high degree of value - by develop new processes, for example.

Programmers and modellers (and technicians) - are relatively easy to find. They add little value - there is no innovation at this level - and just follow a process. They must have a high level of technical skill in their area of specialty.

Enablers

Technology -

- Virtools 3D content creation software
- 3D Studio Max
- Maya software
- Adobe Photoshop
- Database & storage systems
- Computer processing power & operating environments
- Sophisticated graphics cards

Display technology -

- Projection systems
- Curved screens
- Stereo passive glasses
- Interfaces/support technologies (Cat5 etc - long distances)
- Blending software (to stitch images)

Asset database of Videos, digital photos, CAD drawings and 3D model library

People - with the right reputations, relationships and skills

- Business/Production Manager
- Sales/Consultant
- Programmers
- 3D Modellers

Technical support

- People for hardware support (software is supported over the phone or online)
- Admin support

Time frame for new model - 8 weeks using existing digital assets for a complete mine (small section can be produced in 2-4 weeks)

- Includes Scope and design - 1 week

- Testing phase and feedback - 7-10 days
- Liaison, planning, scoping, high-level technical detail

Required Competencies

Scoping - gathering info, designing solution, understanding needs, i.e. competency based training

Creating solutions - creating models, interaction, creating the trainee's experience

Adapting the models to various delivery systems

Gathering experience - continuous improvement successful delivery of better outcomes

Risk Analysis

Issues

Indemnity - the risk of liability for damages to (and caused by) trainees in the workplace needs to be carefully managed, with indemnities for the VRGroup from the organisations that supply and/or sponsor the training on which the simulations are based.

Cost/Benefit analysis for training providers? The JCB has ordered $4.2M of iDome display equipment - how many trainers would this employ?

Speed of production -

- It currently takes a long time to build individual modules, but this will decrease as programmers and modellers become more familiar with the modelling software and processes and as the Digital Asset database builds.
- The production process needs to be automated. This would significantly reduce the time, and therefore cost, to produce models.
- Manufacturer's CAD drawings would streamline process (IP is an issue for information-sharing)

Standardised process - need a standard specification for input and programming (currently an inefficient process)

Quality and speed to market - the computer game industry sets the standard and expectations of trainers and trainees.

Deployment issues - demands of 3D immersive delivery system complicates implementation adds significantly to the cost.

Switching costs - currently switching costs are high. Immersive systems more difficult to replicate than flat-screen presentations. To maintain its market leadership position the VRGroup must continue to innovate to provide the best possible solution for a given price.

Ability to copy - because content is delivered digitally it is not difficult to copy. The VRGroup needs to carefully license installation sites to reduce the risk of copying and to increase switching costs.

Cost of licensing - for the software used for producing and viewing content is significant. There is a risk that a competitor could use cheaper software to produce competing content at a much lower price.

Skill in maintaining systems - requires knowledgeable technicians. 100% up-time essential - clients will expect SLA's with service guarantees.

Expectations of trainees - looking for realism - comparing against game quality.

People - there is a risk of ‘poaching’ people - at high and low levels of the organisation.

Limitations - there is a limit to the utility of 3D training - at some point you have to get your hands dirty.

Finance Summary

Expense Budget

Salaries - the largest expenses in this business are salaries.

- **Business Manager** - in this Budget the VRGroup is assumed to be a standalone business with the Business Manager attracting a full-time salary of $150,000PA (plus Super and Motor Vehicle). If the VRGroup were to become part of a larger business, in which a manager only allocated a part of his or her time to running the Group, salaries would be correspondingly lower.
- **Sales/Consultant** - is a senior manager with a salary of $150,000 (plus Super and Motor

Salaries	Base Salary	Superannuation	Expenses	Annual Salary
Business Manager	$200,000	$18,000	$25,000	$243,000
Sales/Consultant	$150,000	$13,500	$25,000	$188,500
Programmer	$100,000	$9,000	$5,000	$114,000
3D Artist	$80,000	$7,200	$2,000	$89,200
Admin Assist.	$35,000	$3,150	$0	$38,150

Vehicle)

- **Programmers and Artists** - are expected to have relatively fixed salaries of $100,000 and $80,000 each, respectively.
- **Administration Assistant** - has been budgeted at $35,000PA, if the VRGroup were to become part of a larger business this might be a shared resource at a correspondingly lower cost.

Occupation Expenses - are based on 150m^2 in Western Sydney, where rents per meter (using Norwest as an example) are approximately $300/m^2 per annum.

Equipment and Software - the cost PA is based on the approximate cost of the equipment capitalised over three years - an estimation of the impact on cash flow, not profit.

System support costs - are the estimated costs of tech support for over $100,000 worth of mission-critical computer hardware, plus telephone and internet costs.

Expense total - is an estimate of the cash required for the first year of operation as a stand-alone commercial enterprise - $1,730,683.

Research - included is an indicative figure of $250,000 (to be negotiated) representing an annual Research Grant to the UNSW School of Mining Engineering.

License Fees - also included is an annual License Fee, payable to the UNSW as a percentage of Gross Sales.

Not included - in this estimate are start-up costs, including legal and other fees.

Sample Project

The following chart provides an indication of the actual cost of producing a real training module. This module was produced within the UNSW lab, and reflects the cost of labour but not the cost of occupation,

Mine Model - 100m	Employee	Production Time (Days)	Salaries Cost
Determine Specification	Consultant	6.0	$5,140
Build 5m Sections	3D Artist	39.0	$15,813
Placement & Importing	3D Artist	5.5	$2,230
3D Assets into Virtools	Programmer	0.5	$259
Virtools Composition Setup	Programmer	15.0	$7,775
Interaction	Programmer	0.5	$259
System Configuration	Programmer	1.0	$518
			$31,994
Shuttle Car (Basic, no animation or physics)			
Determine Specification	Consultant	0.5	$428
Collect photos etc	Consultant	1.0	$857
Model & Texture	3D Artist	7.0	$6,081
Placement & Importing	3D Artist, Programmer	0.5	$203
Interaction	Programmer	8.0	$4,145
			$11,714
General Interaction			
Setting up a Basic Hazard	Programmer	1.0	$518
Setting up an Effect Shader	Programmer	2.0	$1,036
			$1,555

equipment, or other non-salary expenses.

The Time Required is based on a detailed analysis of the actual time invested in a real project - a VR Training Simulation module commissioned by the Joint Coal Board. This module included 100m of Mine, a Shuttle Car model, interaction with various pieces of equipment and hazards, and interactive training:

Production Efficiency

The most significant enablers of production outputs for this labour-intensive business are:

3D Production Software - increases in the efficiency of modelling software will significantly reduce the time taken to produce each module,

Digital Assets Library - each new project provides an opportunity to add to the library of reusable Digital Assets (photos, drawings and complete 3D models), and

Programmer knowledge and skill - as operators become more knowledgeable and skilful the time that they take to complete each project will be significantly reduced.

Conclusion

This plan outlines the potential for the VRGroup established by the UNSW School of Mining Engineering to become a commercial enterprise, either as a standalone business or as part of a larger company.

The know-how developed by the School will enable the VRGroup to capture a significant share of a growing market for sophisticated training solutions. With projects already successfully completed and with future orders in hand the VRGroup is developing a reputation as a supplier of high quality immersive training materials.

The success of the VRGroup is dependant on:

Its ability to identify training needs and develop tailored solutions that provide better outcomes than conventional training methods,

Access to industry, particularly the mining industry, to enable the VRGroup to develop immersive training simulations and develop new markets,

A close relationship with the University of NSW, which carries the reputation as one of Australia's leading Universities and provides access to emerging technologies through world class research, and

Technology that continues to improve, providing trainees with immersive training experiences that provide high quality training in a safe environment

Next Steps

The projected revenues and expenses in this plan are based on known and estimated future sales opportunities for the VRGroup. Potential investors and business partners should conduct their own research to determine the potential market and revenue opportunities for the VRGroup. ***It should be noted that the projections are purely speculative and not based on formal leads.***

Appendix D:

Assessing Levels of Immersive Tendency and Presence Experienced by Mine Workers in Interactive Training Simulators Developed for the Coal Mining Industry.

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Abstract. The School of Mining Engineering at the University of New South Wales (UNSW) is developing and deploying immersive, interactive simulations to the Australian mining industry. Industry is concerned that many rules and regulations have been implemented to improve safety and work procedures resulting in a significant improvement in safety in recent decades. However, accidents and injuries continue to occur - sometimes with serious consequences. Interactive computer based visualisation of mine environments has the potential to improve safety through improved understanding of mine environment hazards, procedures and processes relating to day-to-day operations. This improvement is achieved by engaging trainees with a virtual mine environment that closely represents the mine in which they will operate. The ultimate aim of the project is to improve Occupational Health & Safety performance through the provision of more effective education, training and assessment for mine workers. The focus of the project is human interaction with mine environments and it is proposed that increased levels of immersion and presence in virtual mines will assist in the perception of hazards and also help gain acceptance by the mining industry. A goal of the training simulation development is to present high resolution and fidelity within the virtual mine environments. The simulation modules are based on key aspects of the learning outcomes prescribed by the core-competencies for mine workers. Trainees address these learning outcomes via problem-based learning exercises performed within the modules. The paper presents a preliminary study on the Immersive Tendency and Presence that mine workers experience during exposure to the simulations and discusses the results. The data was collected at Newcastle Mines Rescue Station and includes a range of mine workers from new starters to experienced personnel.

Introduction

In recent decades masses of rules and regulations relating to mining operations have been introduced. A great reduction in accidents and injuries in Australia has been the result. However, accidents continue to occur and it is suspected that the shear volume of data and rules and regulations that must be implemented and understood by mine workers in day to day operations may be too voluminous to comprehend and fully implement [1]. Also, underground and surface mining operations present a complex and dynamic 3D problem to engineers and mineworkers. The dynamic nature of the environment is such that hazards and unforeseen safety issues can arise on a regular basis. Training new and experienced mine workers on site to deal with these situations is often difficult from a risk management perspective. Virtual training environments provide a training method that is safe and forgiving and that allows miners to gain experience in infrequent or routine mining processes.

Virtual Training simulation for the mining industry was pioneered at the University of Nottingham in the UK where low cost simulator software was developed. [2,3] This type of 'games' based simulation has steadily progressed and improved over the past fifteen years to a form where the technology is now widely available to industry at all levels of entry.

Training within Virtual Mine Sites

Training of mine workers at mine sites and training centres in New South Wales is often performed via conventional classroom methods using PowerPoint presentations and white boards. Practical training is also involved at some centres. Training via these methods may not be the most appropriate for mine workers who are required to show competence in a certain area before they can be considered competent for mine-site operations. Early work in VR training for mine workers in South Africa [3] showed that using VR training over conventional classroom methods ensured that trainees had to interact with the environment to progress to a successful outcome. Inattention does not allow success – unlike some conventional group training methods. That is, interaction with the environment promotes more engagement with the material and forces the user to think about the consequences of their actions. This is particularly pertinent for mine workers where mistakes can be fatal. Also, the manner in which training material is delivered in the classroom causes concern. It is frequently assumed that presenting the same material in written and spoken form benefits learning and understanding. This may not be the case [4] and interactive VR training may present a more efficient method for training people in the mine environment where a visual representation of the environment enhanced with interactive decisions is used to teach trainees on the hazards and processes involved in mining.

The University of New South Wales (UNSW) in collaboration with industry has progressively built simulators for the coal mining industry. [1] The simulations were developed from a technical concept derived though industry consultation and development of a hybrid system. [5]. The simulations have been deployed at Mines Rescue Stations in New South Wales and are in daily use for training in areas such as Unaided Self Escape, Rib and Roof Stability, Hazard Awareness and Isolation. The objective is to simultaneously train groups of miners in an environment where they are exposed to high resolution, 'on to one' scale visualisation of the underground environment in which they will operate. The main objectives are to make trainees feel as though they are located in the mine and provide them with a fully immersive experience.

Presence Mine Training Environments

Training mine workers in the real environment is extremely difficult due to safety and logistical issues. During training, it is important that miners are provided with information, knowledge and experience of the mine environment in which they will work so that they can build up and demonstrate competency. The ideal training situation would be an exact copy of the particular mine environment in which miners will operate. On a small generic scale this is practicable, however, producing a complete representation of every mine into which groups of trainees can be placed is less so and it is difficult to alter these physical mines quickly and easily so that subtle and significant differences between one mine site and another can be represented. High resolution virtual mine training environments provide the flexibility to achieve the required look and feel of specific mines. An example is shown in Figure 1.

Figure 1: Example Mine Simulation.

Also, the requirement for trainees to feel immersed and experience presence – that is, "The subjective experience of being in one place or environment, even when one is physically located in another" [6] – is considered important as the miners need to gain experience that translates to the real world. In the virtual environments described in this paper, presence refers to experiencing the computer generated environment rather than the actual physical locale [7]. In this case, the environments are computer based virtual mines as shown in Figure 1 and 2. Until recently, training of mine workers was performed by conventional training media, such as PowerPoint presentations, videos and lectures interspersed with limited hands on training. Research has shown that these techniques are not always the most efficient for learning and can interfere with learning [4]. It is believed by the authors and literature that a strong sense of presence is linked to the quality of training [6]. An objective of the UNSW mining project is to provide a sense of presence to mine workers during training so that they feel as though they are underground and not necessarily in a classroom environment. The need for such a high level of presence is required for two reasons, the first is that trainers require a high resolution mine model in which trainees can be placed that looks and reacts as a real mine would. The second is that many highly experienced miners can provide high level experience that can be placed into the model environment. This experience must be recorded for future generations of workers, however, to extract the subtle details that are important to ongoing safety, the experienced mine experts must see the model as a real mine and experience presence to accept it as a training tool and be able to conceptualise mining practices – good and bad that are to be placed in the virtual mine for training purposes. Many features are small scale and it is proposed that high levels of presence will improve the experience given to the mine workers and experts with respect to these issues in particular. Another key issue is the practicality of some mine safe work procedures, which as the project progresses are manifesting as impracticable. These processes are now being reviewed by mine experts who can now collaborate in the virtual environment to improve these procedures. Spatial awareness in the mine environment is also a key factor relating to safety where large machinery and unstable ground is often encountered.

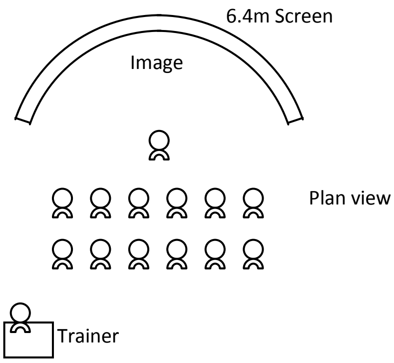

Figure 2: Mining Simulator Layout.

Data Collection

The project is a preliminary study and it was intended to collect an initial data set to assess the level of presence experienced in mine workers exposed to a new 160 degree curved screen system installed at a Mines Rescue Station in New South Wales (Figure 2).

The main objectives of the experiment were to use known experimental data collection methods and processes to assess the presence and immersive tendency of the mine workers whom experienced the simulations; get the trainers used to collecting data during their training programmes and generally gain insight into the people that attend the mine training courses. Presence is believed to influence training outcomes for users and many of the factors which appear to affect presence are know to enhance learning and performance [6]. The data was collected using established questionnaires developed by Witmer and Singer [6, 7]. Data was collected manually by the trainers over two months.

Trainees Surveyed

Fifty one trainees from different mines, contractors and companies were surveyed over two months. Completion of the survey was optional. All the trainees were male. Their age ranged from 19 to 57 years mean age was 31.3 years (SD 8.74). Most trainees were new starters. Their experience ranged from 0 to 30 years (majority having no experience) Average years experience 3.11years (SD 7.22).

Procedure for Measuring Presence

Witmer and Singer [6] developed two questionnaires that have been used widely to assess presence. They are the Immersive Tendency Questionnaire (ITQ) and the Presence Questionnaire (PQ). The factors that are hypothesised by Witmer and Singer [6] to contribute to a sense of presence are shown in Table 1. The ITQ was completed by the trainees immediately prior to observing the simulation. The ITQ considers factors such as Involvement: Tendency to become involved in activities, Focus: Tendency to maintain focus on current activities and Games: Tendency to play video games. The PQ was completed immediately afterwards and measures major factors such as Control factors, Sensory Factors, Distraction Factors, Realism Factors relating to the trainee's perception of the display system features. The trainees were shown mine models in which they had to navigate the virtual mine, locate hazards and respond correctly to those hazards. The consequences of interaction with the model were shown to the trainees. During training, one trainee navigated the model and the rest of the group observed. Group size was generally 10.

Table 1: Factors hypothesised to contribute to a Sense of Presence [7]

Control Factors	Sensory Factors
Degree of Control	Sensory Modality
Immediacy of Control	Environmental Richness
Anticipation of Events	Multimodal Presentation

Mode of Control	Consistency of multimodal information
Physical environment modifiability	Degree of movement perception. Active search
Distraction Factors	**Realism Factors**
Isolation	Scene realism
Selective attention	Information consistent with objective world
Interface awareness	Meaningfulness of experience
	Separation anxiety / disorientation

Results

The results of the presence questionnaire (PQ) item analysis are presented in Table 2. At this stage the questions were relatively unmodified from those presented by Witmer and Singer [6, 7] to identify repeatability in the experiment. A Sensory Factor question was added to identify if miners felt dizzy during the experiment. The question's relevance to the assessment of presence in virtual environments is discussed in detail by Witmer and Singer [6, 7]. Tichon et al [8] applied a modified survey to survey a small population of rail workers with some success, however, for the purposes of this experiment the original item sets were considered more relevant to the mine workers and further work will result in some modification or review as experienced and implemented by Tichon et al [8].

Table 2 shows the Presence Questionnaire PQ Item Analysis. 12 of the 14 control factors correlate significantly with the PQ total score. Item 1 does not correlate, probably due to most trainees in the groups being observers. Item 32 has a low correlation suggesting that some trainees did not remain aware of the time in the simulation. 11 out of the 12 sensory factors correlate. Item 33 did not correlate suggesting few participants experienced motion sickness. However, more studies will be performed on this. All 7 realism factors correlated with the overall PQ score. 5 of the 6 distraction factors correlated significantly with the PQ overall score. Item 8 had a low correlation suggesting that some trainees were unaware of the real world around them. The items on the PQ scale were mostly derived from original factors determined by Witmer and Signer [7]. These factors enable experienced presence to be measured. However, these early results should be treated as a such, there was a great deal of anticipation in the trainees who experienced the new simulator technology and as such, the responses to many of the questions were positive despite the trainees not being able to fully interact with the environment as shown in item 17 at that stage. They could indeed survey the environment using touch via a touch screen and joystick. However, they could not 'touch' the actual image on the screen. The distraction factor items correlated except for item 8. This may be due to distractions outside the simulation session that divert trainee's attention. The facility is placed in a working mines rescue station. The PQ items 5, 6, 10, 18, 23 and 32 were included by Witmer and Singer [7] to assess involvement. Involvement in simulator training is extremely important to achieve presence. All items correlate suggesting high levels of involvement except for 32 which has a low correlation thus suggesting that some trainees were still aware of the time whilst in the simulator. The simulation contained objects that were moving and also moved trainees in vehicles to simulate transport in mine vehicles. This was measured by item 10 and 18 where trainees the sense of object or themselves moving was compelling.

Table 2 PQ Factors

PQ Item Stem	Factor	ITCorr
1 How much were you able to control events?	CF	-0.055
2 How responsive was the environment to actions that you initiated (or performed)	CF	0.743
3 How natural did your interactions with the environment seem?	CF	0.900
4 How completely were all of your senses engaged?	SF	0.922
5 How much did the visual aspects of the environment involve you?	SF	0.983

6 How much did the auditory aspects of the environment involve you?	SF	0.980
7 How natural was the mechanism which controlled movement through the environment?	CF	0.837
8 How aware were you of events occurring in the real world around you?	DF	0.595
9 How aware were you of your display and control devices?	DF	0.956
10 How compelling was your sense of objects moving through space?	SF	0.932
11 How inconsistent or disconnected was the information coming from your various senses?	RF	0.775
12 How much did your experiences in the virtual environment seem consistent with your real-world experiences?	RF,CF	0.889
13 Were you able to anticipate what would happen next in response to the actions that you performed?	CF	0.941
14 How completely were you able to actively survey or search the environment using vision?	RF,CF,SF	0.859
15 How well could you identify sounds?	RF,SF	0.792
16 How well could you localise sounds?	RF,SF	0.974
17 How well could you actively survey or search the environment using touch?	RF,SF	0.754
18 How compelling was your sense of moving around inside the virtual environment?	SF	0.915
19 How closely were you able to examine objects?	SF	0.708
20 How well could you examine objects from multiple viewpoints?	SF	0.876
21 How well could you move or manipulate objects in the virtual environment?	CF	0.944
22 To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	RF	0.762
23 How involved were you in the virtual environment experience?	RF	0.704
24 How distracting was the control mechanism?	DF	0.864
25 How much delay did you experience between your actions and expected outcomes?	CF	0.922
26 How quickly did you adjust to the virtual environment experience?	CF	0.807
27 How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	CF	0.920
28 How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	DF	0.905
29 How much did the control devices interfere with the performance of assigned tasks or with other activities?	DF,CF	0.964

30 How well could you concentrate on the assigned tasks or required activities rather than mechanisms used to perform those tasks or activities?	DF	0.930
31 Did you learn new techniques that enabled you to improve your performance?	CF	0.966
32 Were you involved in the experimental task to the extent that you lost track of time?		0.475
33 Did you feel dizzy during the simulation?	SF	-0.211

The results of the immersive tendency questionnaire (ITQ) item stem analysis are presented in Table 3. Again, at this stage the questions were unmodified from those presented by Witmer and Singer [6]. This was to assess repeatability in the experiment and it was believed that the questions themselves would reveal some interesting data about the trainees who were experiencing the simulations. The ITQ Item analysis shows that 20 of the 29 items correlated significantly with the ITQ total score. 9 items did not correlate significantly these were items 4, 7, 10, 11, 12, 20, 21, 26 and 28. Witmer and Singer [7] contest that the ITQ is measuring a single construct which is, the tendency to experience presence. The authors concur with this and the high levels of correlation in the mining data suggest this is so. However, the low number of participants (51) in the study means that the data should be considered for what it is - a preliminary survey. Larger numbers of participants that will be surveyed in the simulators may alter the correlation. Item 4 in the mining data and original data did not correlate suggesting this may not be an appropriate question. Item 7 relates to focus and did not correlate suggesting that either the trainees were not challenged by the simulator, or had become bored with the conventional course material they experienced prior to experiencing the simulator. This will be addressed through course design. Item 10 is interesting and suggests in some cases that the use of video games provides a ‘window’ into the virtual world and does not place the trainee into the environment such that they experience immersion and presence. The project’s goal is to make the trainees feel as though they are in the mining environment. An alternative answer to this is that the trainees don’t use video games at all outside of training. Item 11 did not correlate at all, however, it is still relevant as on of the key issues in mining is the volumes of text provided as safe work procedures. Miners do not appear to read books and this could be a serious issue when most of the information provided to them is in text based form. Item 12 produced no data for computation. Item 20 did not correlate suggesting that enjoyment may not be directly related to experiencing presence. Item 21 suggests that trainees do not generally play video games which relates to the answers of item 10. Item 26, 28 had a low correlation that may be a result of the demographic and the industry culture.

Table 3 ITQ Factors

PQ Item Stem	Sub scale	ITCorr
1 Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?		0.396
2 How easily can you switch your attention from the task in which you are currently involved to a new task?		0.311
3 How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?		0.738
4 How well do you feel today?		0.114
5 Do you easily become deeply involved in movies or TV dramas?	Focus	0.810
6 Do you ever become so involved in a television program or book that people have problems getting your attention?	Invol	0.753

7 How mentally alert do you feel at the present time?	Focus	0.183
8 Do you ever become so involved in a movie that you are not aware of things happening around you?	Invol	0.768
9 How frequently do you find yourself closely identifying with the characters in a storyline?	Invol	0.741
10 Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?	Games	0.182
11 On average, how many books do you read for enjoyment in a month?		NA
12 What kind of books do you read most frequently? (CIRCLE ONE ITEM ONLY!)		NA
13 How physically fit do you feel today?	Focus	0.303
14 How good are you at blocking out external distractions when you are involved in something?	Focus	0.581
15 When watching sports, do you ever become so involved in the game that you react as if you were one of the players?		0.880
16 Do you ever become so involved in a daydream that you are not aware of things happening around you?	Invol	0.883
17 Do you ever have dreams that are so real that you feel disoriented when you awake?	Invol	0.444
18 When playing sports, do you become so involved in the game that you lose track of time?	Focus	0.798
19 Are you easily disturbed when working on a task?		0.633
20 How well do you concentrate on enjoyable activities?		0.094
21 How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)	Games	0.080
22 How well do you concentrate on disagreeable tasks?		0.753
23 Have you ever gotten excited during a chase or flight scene on TV or in the movies?	Focus	0.733
24 To what extent have you dwelled on personal problems in the past 48 hours?		0.488
25 Have you ever gotten scared by something happening on a TV show or in a movie?	Invol	0.691
26 Have you ever remained apprehensive or fearful long after watching a scary movie?	Invol	0.141
27 Do you ever avoid carnival or fairground rides because they are too scary?		0.738
28 How frequently do you watch TV soap operas or docu-dramas?		0.121
29 Do you ever become so involved in doing something that you lose all track of time?	Focus	0.713

Discussion

A preliminary experiment has been performed that presented mine worker trainees with a simulated environment of an underground mine. The experiment was set up to be repeatable and set a baseline from which to develop more sophisticated assessment methods. The mine shown to the trainees is high resolution and the trainees must interact to progress through the environment and be successful in the training objectives. The trainees were exposed to two key modules. That is, practice self escape procedures and routes and be aware of rib and roof stability issues. In a effort to gain acceptance, a great deal of effort has been expended to build high quality models and provide a projection system that gives a one to one scale image for the trainees to experience. The projection system is still developing. The original idea was to train groups in the environment and provide them with group based learning exercises. Due to the nature and severity of the consequences of bad decision making in mines, the trainees must be shown a virtual environment that is as close to the real environment as possible. There are two key reasons for this, the first is that the mining industry's expectations of what simulation should provide are very high and anything that doesn't look real is not taken seriously. Industry experts are essential in providing information during development. The second is that many of the most dangerous indicators of hazards are very small scale and subtle. For the untrained or inexperienced, they can be easily missed with serious consequences. Looking at these hazards by conventional means (photos, videos, etc) appears to have limited transfer to the real world. Showing these hazards in a virtual environment where a person is experiencing presence and one where trainers can point them out and explain a particular hazard and get trainees to remedy them 'by doing' whilst present in the virtual environment, must improve understanding. Having presence in and interacting with the virtual environment and having the trainee make natural responses must aid learning. The early results suggest that the systems are providing presence and immersion and that continued work will improve knowledge and understanding in mine workers.

Conclusions

Mining is a high risk industry that requires highly trained and experienced personnel to maintain safety standards. However, gaining experience in real mines exposes people to risk. Virtual training environments provide a safe and forgiving environment in which experience, knowledge and skills can be obtained. Practising these skills leads to and maintains competency. Conventional classroom methods work under many circumstances, but in some instances they are inappropriate and allow inattention by the trainee. Their effectiveness is also sometimes questioned. As a process of continual improvement, UNSW has developed interactive virtual training environments into which groups of miners can be placed to learn and build up experience of mining environments. To provide the high levels of interaction and transfer of knowledge from industry experts and trainers to trainees, high resolution virtual environments are required and high levels of presence are required to make the trainees feel as though they are underground while in fact, they are actually at a Mines Rescue Training Facility. To begin to assess the level of presence and immersive tendency experienced by the trainees during virtual mines training sessions, an experiment was performed based on established procedures. These procedures were implemented relatively unchanged to demonstrate repeatability and subsequently showed that they were in fact highly repeatable. The experimental results showed that mine trainees who viewed the simulations did experience high levels of presence and had immersive tendencies that caused them to be involved, focussed on the simulation and become immersed in the environment. The correlation and presence were in many cases higher than the original work. However, this may be due to the demographic of the data set. While the system of assessment for the tasks is still being developed, anecdotally, the trainers report a more meaningful experience is presented to the trainees in the form of a visualisation of the underground environment. This in itself may be the reason for a higher level of presence and immersion and will be tested in future work. An interesting feature of the data is that the mine workers surveyed, don't really read books or watch TV. Given that current training methods rely on text and videos in PowerPoint presentations etc, it would appear that a more interactive approach to training that involves and immerses trainees in the virtual environment is more likely to successfully transfer knowledge and skills and improve long term safety.

Further Work

Since beginning the project in 2005, the format of the simulator has moved from 160 curved screen to a 10m diameter by 4.0m high 360 projection system which the authors believe will increase levels of presence significantly. In this system the trainees are completely surrounded by the image. Data is being collected automatically via online survey rather than manually to ensure all participants (or as many as possible) contribute to the survey. This data will be compared to the data collected for other screen formats and presentation platforms.

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