Improving Mine Safety and Mining Education through use of virtual reality

Dr Rudrajit Mitra*, Prof Bruce Hebblewhite & A/Prof Serkan Saydam

School of Mining Engineering,
The University of New South Wales, UNSW Australia, NSW 2052 Australia
(* Corresponding Author: r.mitra@unsw.edu.au)

The University of New South Wales (UNSW) has been a world leader in the development of innovative virtual reality technologies over the last 10 to 15 years. These developments have included developing the world’s first 360° surround, virtual reality (VR), stereo projection theatre system known as AVIE (Advanced Visualisation and Interactive Environment), which was developed by iCinema, a collaborative venture between the UNSW Faculties of Engineering and College of Fine Arts. The School of Mining Engineering at UNSW Australia has developed and deployed immersive, interactive simulations widely within the Australian mining industry and the mining engineering education sector and are now being adopted internationally. Till date, the School has developed eighteen different mine safety training and mining engineering education modules which run in the AVIE environment.

Industry, across the world, has been 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 has been achieved by engaging both industry personnel and students with a virtual mine environment that closely represents the mine in which they will operate. The ultimate aim of the project was to improve Occupational Health & Safety performance through the provision of more effective education, training and assessment for mine workers.

This paper presents an overview of the innovative technologies involved in these virtual reality systems – as applied to the mining industry. Modules developed for both mineworker training and mining engineering student learning will be presented, to illustrate the effectiveness and value of such a training and education approach.

KEYWORDS
Innovative mine safety training, Mining engineering education, Virtual reality

1. INTRODUCTION

Training of personnel is a very important component of the mining industry around the world. These can range from initial training for new workers to those for experienced people. Industry training is particularly high on the agenda of the Australian mining industry, not only for increasing skill levels across an expanding industry workforce, but also, most importantly for ensuring the highest possible level of mineworker awareness concerning safe (and unsafe) mining practices in relation to the jobs that they will be, or are already involved in. Australian mining companies are investing in large sums of time and money for training to ensure that all personnel who work or visit their mines are aware of the mine environment around them; fully understand the safe work practices employed; but also develop an active safety-focused culture. To this end, the more effective the training can be, the better these goals are achieved and the result is a much safer mine workplace for all (Hebblewhite et al., 2013)

For introductory training in hazardous places such as underground mines, simulations provide an environment that, among other things, is completely safe, well-controlled for optimal instruction, and
less expensive than taking trainees to the work site and interrupting production. Zhang et al., (2011) has discussed that the key to all simulations is the interactive experience gained by the trainees. However, high-resolution and high-fidelity simulations are themselves expensive to construct. They must be used at an optimal capacity to ensure a return on investment. Nevertheless, the cost of such facilities when compared to the loss of a human life or debilitating injury is insignificant.

According to Squelch (2001), Virtual Reality (VR) can be defined as *3D computer generated representations of real or imaginary worlds with which a user can have real-time interaction and experience some feeling of being present in those worlds.* VR training has a number of advantages over existing traditional methods including a larger amount of data collection during training, comprehensive review of a participant’s performance, and systematic development of a trainee’s skills. VR simulators are commonly used to train for hazardous environments in a manner that minimizes the exposure of a trainee to real risk (Nutakor et al., 2007). According to Stothard et al. (2008), the main objectives are to make trainees feel as though they are located in the mine and provide them with a fully immersive experience.

Meyers and Jones (1993) reported that students who use simulations are “forced to think on their feet, question their own values and responses to situations, and consider new ways of thinking”. According to Brookfield (1990), the effects of simulation and role playing on students “involves the whole person-intellect, feeling and bodily senses - it tends to be experienced more deeply and remembered longer”.

Squelch (2001) concluded from his evaluation work in South Africa that VR technology has the potential to provide effective training systems relevant to the South African mining industry. Mallet and Unger (2007) summarises in their paper the organisations involved in VR in mining industry. These organisations were representative at the 2006 Virtual Reality in Mine Training Workshop which was held in Pittsburgh. Mallet and Orr (2008) mentioned the Underground Coal Mine Map Reading Training in their paper in the First International Future Mining Conference, 2008. Lucas et al. (2008) conducted research to prevent injuries and fatalities related to conveyor system by the use of virtual environments. The research was funded by The National Institute of Occupational Safety and Health (NIOSH) to improve training and help miners better understand the hazards of working around conveyor systems. Similarly, McMahan et al. (2008) researched on training workers in pre-shift inspections of haul trucks to avoid preventable defects from causing worker injuries and expensive equipment damage. Stothard et al. (2008) developed a taxonomy providing insight into where technology can and may be implemented in the future, as virtual environments are a dynamic and evolving technology. This taxonomy will assist in the decision making process when scoping or selecting technology for a particular purpose. The University of Queensland (Australia) has also been active in developing virtual reality applications for the minerals industry in the areas of data visualisation, education and training, environmental monitoring application, accident reconstructions, simulation application and hazard awareness applications (Kizil 2003; Kizil et al., 2004; Kizil 2007).

Stothard and Swadling (2010) and Mitra and Saydam (2011) performed literature review studies to identify the types of computer-based VR simulation technologies that have been developed for the mining industry. This was based primarily on publications by research and development organisations. Table 1 summarises the results from these studies.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Simulation</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIMS</td>
<td>Underground and surface mine operations and equipment</td>
<td>Visualisation, safety, design, risk management, hazard identification and remediation</td>
</tr>
<tr>
<td>SIMRAC</td>
<td>Underground goldmine stope model</td>
<td>Safety and hazard recognition</td>
</tr>
</tbody>
</table>

Table 1. Simulation in mining (Source: Stothard and Swadling, 2010; Mitra and Saydam (2011)
<table>
<thead>
<tr>
<th>University</th>
<th>Project Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennsylvania State University</td>
<td>Underground coal mine Safety and hazard recognition</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Underground coal mine data Web based disparate mine data visualisation</td>
</tr>
<tr>
<td>NIOSH</td>
<td>Underground coal mine Hazard identification and remediation</td>
</tr>
<tr>
<td>MIRARCO</td>
<td>Underground mine Mine machinery, geology, geochemistry</td>
</tr>
<tr>
<td>MISC</td>
<td>Surface environment Hazard awareness</td>
</tr>
<tr>
<td>THALES</td>
<td>Underground hard rock Teleremote control</td>
</tr>
<tr>
<td>DMT</td>
<td>Operator training Equipment operation training and visualisation</td>
</tr>
<tr>
<td>Tshwane University of Technology</td>
<td>Underground platinum mine Hazard identification and remediation</td>
</tr>
<tr>
<td>University of New South Wales</td>
<td>Underground coal mining, surface coal mining, uranium mining, ViMINE</td>
</tr>
<tr>
<td>University of Queensland</td>
<td>Surface and underground mining Visualisation, equipment operation, experimental analysis, hazard spotting.</td>
</tr>
</tbody>
</table>

2. EDUCATIONAL MOTIVATION USING SIMULATIONS IN ENGINEERING

It has been observed that students learn best when a variety of teaching methods are used, and that different students respond best to different methods (Bell and Fogler, 1995). Figure 1 shows the average retention rates of various teaching and learning methods. VR based techniques have the potential to revolutionise education in the mining industry when used in conjunction with contemporary teaching techniques such as class discussions, group projects and problem-based learning. According to Kerridge et al., (2003) these education techniques are more attractive to students as they are flexible, attractive and easier to understand - especially in mining where it can be difficult to demonstrate complex mining methods through the use of two-dimensional diagrams.

![Figure 1. Average retention rates (Kizil, 2004)](image)

Further, in addition to traditional base of mathematics and engineering technology, future mining engineers require a new set of skills (MCA, 1998) such as to undertake identification, formulation and solution of problems; utilise a systems approach to design and operational performance; function effectively as individuals and as part of a multi-disciplinary team in roles of both leader and team member; understand and achieve responsibilities socially and environmentally; apply the principles of sustainable design and development; and undertake life-long learning. These skills represent several of the core professional engineering competencies required by Engineers Australia. They require the ability to make technical specialist decisions and at the same time take into account the wider implications of being in a complex dynamic, often messy and unpredictable, socio-political and environmental context, often referred to as ‘systems thinking’ (Saydam et al., 2011).
3. VIRTUAL REALITY DEVELOPMENT AT UNSW

In collaboration with industry, UNSW has progressively developed a VR capability – both for the mining industry, and for mining education purposes. An initial project commenced in 1999 with seed funding from UNSW and Coal Services Pty Ltd. Subsequently in 2002, funding was provided from industry through the Australian Coal Association Research Program (ACARP). A UNSW-developed flat screen ‘proof of concept’ system was deployed at Newcastle Mines Rescue Station (NMRS) in Argenton, NSW. Stothard et al. (2004) described the development, deployment and implementation of a VR simulation capability by the School of Mining Engineering to address the specific needs of the Australian coal mining industry. The simulation capability developed is a hybrid system designed to provide simulation technologies to operators, on various different hardware platforms. The UNSW hardware, plus software applications modules were deployed at four Mines Rescue Stations across New South Wales (NSW) and are currently in daily use for training in topics 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, ‘one to one’ scale visualisation of the underground environment in which they will operate.

The School has been involved in UNSW’s award-winning iCinema Advanced Visualisation and Interaction Environment (AVIE) project – a 3D 360° virtual reality stereo-projection facility and iDOME (a 2D version of the AVIE) (Stothard et al., 2008). The School has constructed an AVIE and an iDOME, funded partly by a Federal Capital Development grant in 2007, for developing mine safety-training simulations. Figure 2 shows the AVIE and iDOME facilities at the School of Mining Engineering.

4. MINING INDUSTRY VR MODULES

The School of Mining Engineering at UNSW initially developed eight (8) modules aimed at training coal mine workers for the New South Wales Mines Rescue Stations. These 8 modules included:

- Hazard awareness,
- Rib and roof stability,
- Self escape,
- Truck inspection,
- Isolation procedures,
- Spontaneous combustion,
- Deputies inspection, and
- Outburst management.
Since the development of these initial modules, various other modules have been developed for the mining industry aimed at safety, community awareness, etc. (Mitra and Saydam, 2011). The following sections provide a brief overview of a selection of these modules.

4.1 Hazard Awareness Module

The Hazard Awareness module was developed to create a general awareness of an underground mine along with spotting hazards as the trainees walk through this environment. This module contains a 3D representation of a coal mine room & pillar development in which 24 hazards are present. These include – coal accumulation under conveyor belt, missing drivehead guards, unsupervised equipment, water accumulation, sagging roof, equipment in unsafe locations, shuttle car operation and traversal of shuttle car wheeling roads, auxiliary fan operation, etc. Similar to the roof and rib stability module, the trainees can navigate through the mine and select areas that are deemed to be hazardous. They are then presented with a series of questions, after which the hazards are fixed. Figure 3 shows some questions that are generally prompted during this module. These questions are helpful for the understanding of their learning.

Figure 3. (a) Question regarding the presence of a hazard

![Question regarding the presence of a hazard](image)

Figure 3. (b) Question on how to control the risk for the hazard identified in (a)

![Question on how to control the risk](image)
4.2 Isolation Module

The Isolation module was developed to demonstrate procedures that people have to undertake in order to rectify a problem. This module contains a 3D representation of a coal mine room and pillar development. The module is split up into 6 sub-modules, each of which allows trainees to follow a mining procedure involving some form of hazard, and examine the issues involved in correct isolation and restoration of energy. These include the following:

- Conveyor belt fines accumulation - A section of the belt must be cleaned.
- Feeder breaker - A large rock has jammed the feeder breaker.
- Continuous miner vent - The continuous miner must be isolated in order to install vent tubes.
- LHD - The steering hose on the LHD needs to be replaced.
- Box & Fan Move - The auxiliary fan & load centre are to be advanced to the next pillar.
- Belt & Fireline Move - The conveyor belt, feeder and fireline are to be advanced to the next pillar.

In this module, the trainees can answer questions and interact with mining equipment. Figure 4 shows some screenshots of this module.

(a) Placing locks and tags                       (b) Verifying installation

Figure 4. Screenshots from the Isolation module

4.3 Outburst Module

The Outburst module was developed to make people aware of what a gas outburst is as well as learn the consequences of the event in order to prevent such events in future. This module contains a 3D representation of a coal mine. The learning methodology in this module is to firstly show trainees what can go wrong if correct procedures are not followed (and thereby quickly gain their full attention in relation to the seriousness of this “high consequence” event). The module presents a virtual reproduction of a catastrophic outburst event, after which students can explore the aftermath. Trainees are then presented with information about outburst management procedures and ten common outburst indicators. They are then able to navigate through a virtual representation of the face and identify the indicators that are present and should have been detected.

5. MINING EDUCATION VR MODULES

The School of Mining Engineering at UNSW has also made use of this technology beyond mine safety training. It has developed educational modules aimed for both undergraduate and postgraduate mining engineering students – again with the objective of improved effectiveness in the teaching and learning experience.
The four major mining education providers in Australia (Curtin University of Technology, The University of Adelaide, The University of New South Wales and The University of Queensland) are part of a national curriculum – Mining Engineering Education (MEA). MEA was established in 2006 with the purpose of undertaking an innovative approach to educating undergraduate mining engineers that meets the demands of the industry in terms of quality and quantity of mining graduates (Saydam et al, 2009; Hebblewhite, 2006 & 2010). As part of this collaboration, various innovative teaching techniques and effective instructional materials were developed. These diverged from the traditional way of delivering engineering education, which has historically been based on lecture-based teaching approaches.

The School has initially developed eight (8) modules which are currently being used across many of the courses - both undergraduate and postgraduate. All these modules are capable of running in the AVIE at the School and also on a standalone PCs or laptops (albeit without the full immersive experience offered by the AVIE). Some of these modules are currently being developed to run on the internet so that students can access them at their leisure. These 8 modules included:

- Mining in a Global Environment
- Laboratory Rock Testing
- Block Caving
- Truck & Shovel
- Longwall Top Coal Caving
- ViMINE
- Seismic Data Monitoring for block caving mining system
- Coal Geology (under development)

The following is a summary of some examples of these educational VR modules.

### 5.1 Mining in a Global Environment Module

This module acts as a virtual site tour of the Ranger uranium mine in Kakadu National Park, located in the Northern Territory, Australia. It contains 16 photographic 360° panoramas of the mine and the surrounding environment, as well as 12 panoramic videos, 4 aerial photographs, 7 interviews with site personnel and industry experts, and over 180 still photographs. Students are able to combine these resources into virtual "workspaces", grouping related information together. Students also have access to an archive of chemical data. The data can be viewed by selecting from a series of "hot spots" on an aerial photograph of the mine and its surrounding areas. In a major group assignment using the AVIE, students firstly asked to review the current mine operation and compare it with issues identified in the original mine “Environmental Impact Statement”. They are then given the opportunity to construct an optimal mine layout for a green-fields site in the same location (Figure 5). They are presented with both an aerial and a panoramic view of a real life site and can construct a mine by dragging and dropping 2D/3D representations of major mine features such as buildings, waste dumps, dams and processing plants. At the end, they have to justify the location of their hypothetical mine layout considering the environment in which they are located, as well as various community and indigenous considerations. Kakadu National Park being a world heritage site adds more complexities to their assignment. The Ranger Mine was chosen for this assignment due to its complexity of issues including environmental, community, cultural, climatic, remoteness, etc. (Laurence and Stothard, 2010).
5.2 Block Caving Module

This module contains the lower portion of a block caving mine containing 60 drawpoints (Figure 6). The purpose of the module is to install ground support around drawpoints on the extraction level. This must also take into account the implications for maximising profitability and output of the mine. As time goes by in the module, the condition of each drawpoint deteriorates and produces less ore. Reinforcing the area with adequate ground support prevents the output from dropping further. Once the user has gone through the entire extraction level, he/she is presented with a score for their session, covering both geotechnical factors, as well as economic and production performances. This module is currently being used more as a game.

5.3 4D Interactive Learning System Approach – ViMINE – Virtual Mine

In the world of digital entertainment, four-dimensional (4D) interactive environments incorporating multiple simulations are common. 4D VR simulations can take participants through time to view the future outcomes of a decision – combining 3D representations of physical situations with other forms of data presentation. Increasingly, integrated simulations are being brought into professional education. The SIMPLE project in the UK (Hughes et al., 2008) has developed integrated simulations for law and related disciplines. There are currently no 4D simulations that integrate professional technical simulation tools with socio-economic models for mining engineering education. ViMINE is a tool that has been developed for mining engineering students to experience various aspects of a mining operation working together, integrating several types of simulation into one environment. In scenario-based learning activities run through the ViMINE environment, students can access information from different simulations and make decisions throughout the life of the simulated mine, from initial exploration to final site rehabilitation and evaluate their effectiveness for building systems thinking skills. Essentially students can experiment with a fully ‘operational’ mine (Saydam et al., 2011).

Figure 5. Students doing the assignment in the “Mining in a global environment” module

Figure 6. Drawpoint in the virtual Block cave mine
ViMINE allows students to carry out a number of mine design projects where they link separate mine planning and design simulation software packages, as part of one simulation exercise – i.e. the results from one simulation tool will flow through to another. The integration of different simulation software takes place in stages, as required for specific learning activities and scenarios.

The ViMINE environment allows students to design various aspects of a mining operation and assess the feasibility of different design options. The outcomes of each simulation will depend on the decisions that students have taken at previous stages in the life of mine. This ability to simulate the whole mining operation in an integrated way is a substantial qualitative improvement over current methods. A number of scenarios have been developed for students to work through in the simulated environment. These scenarios include various technical and socio-economical factors relevant to the mining industry; based on real technical data provided by the industry and including influences such as exchange and interest rate changes, commodity price fluctuations and environmental concerns. With financial support from UNSW’s Faculty of Engineering and the School of Mining Engineering the first two modules of ViMINE were developed in 2011. This included mining method selection and mine design modules using real mine data. Currently, the mining method module will be available on the world wide web and, iPads and other smart mobile devices.

ViMINE mining method selection module is a simple module used for mining method selection in the first year introductory course. Fourteen different terrains are available (Figure 8a) to simulate the various possible surface environments which might exist in proximity to a mineral deposit. These include a range from ideal to extreme conditions. An orebody (real mine data set) is placed under the selected terrain scenario. The depth, orientation, dip and rock characteristics are selected by the instructor to set different scenario for each group. Students then decide on the mining method using their knowledge taking into consideration environment and possible community constraints. In addition, they are able to see some of the possible mining method animations to review their knowledge (Saydam et al., 2011).

A detailed version of this module is being used in a third year course. In this module, students set the terrain and the orebody similar to the earlier version. Additionally, they take into account a more detailed investigation by entering appropriate assumptions using an algorithm, used for mining method selection. The method ranks possible methods based on the assumptions (Figure 8b). Students then take into account the socio-economical considerations to make their final decision on the appropriate mining method based on their scenario.

The second module is the open pit mine module, which focuses on the planning and design for a real metalliferous mine. This module visualises the outcomes of a mine design software package including multiple pushback (cutbacks) schedule scenarios throughout the mine life, equipment selection, project evaluation and environmental constraints. Students are able to design the mine and suitably position the infrastructures based on their technical and economic decisions. In addition they can design the haul roads in and out of the pit (Figure 8) and also select suitable equipment for the designed pit (Figure 9).
5.4 Truck and shovel module

This module contains a library of resources pertaining to truck and shovel operations. The first part acts as a virtual tour of several truck and shovel operations. It contains 23 photographic 360-degree panoramas, 2 aerial photographs, 6 interviews with personnel, 3 full resolution 360° panoramic videos, 15 assorted videos, and almost 400 still photographs. Students are able to combine these resources into virtual workspaces, grouping related information together. Students can also navigate, in 3D, a full digital terrain map of an open cut mining operation at the Hunter Valley, NSW, Australia. The second part of the module is a 3D representation of a sample equipment selection software simulation. Students are presented with an open cut mine and the option to run the simulation using 3, 4 or 5 trucks. The simulation can then be viewed at up to 16x real time speed, from any number of angles, and paused, resumed and restarted. Students are also presented with an overlay displaying the elapsed time, the idle time for the loader and the amount hauled for each truck. With the help of this section of the module, students can visualise in this virtual environment the importance of choosing the correct number of trucks for each shovel. This module also shows the capability of this system to link with other software packages. This technology is currently being undertaken in another project which will be discussed later in this paper. Figure 10 provides a screenshot of the equipment selection simulation that the students can observe in this environment.

Figure 8. Haul road design

Figure 9. Equipment selection

Figure 10. Equipment selection simulation observed in the Truck and Shovel module
6. CONCLUSIONS AND FUTURE OPPORTUNITIES

Simulations, VR and digital gaming technologies have demonstrated their educational value to other industries, confirming the powerful learning opportunities and advantages. It can be said that using simulations enhance student learning and understanding of complex problems. The School of Mining Engineering at the University of New South Wales has developed various Virtual Reality modules for mine safety training for the Australian Mining Industry, and also for mining education and improvement of Learning and Teaching across the major Mining Schools in Australia. Ongoing development in all of these application areas is continuing.

It is clear that the opportunities and potential applications of VR technologies go well beyond current practice. In the field of mine safety training, the ability to use these technologies in parallel with current practices offers the industry significant gains in training effectiveness, and ultimately mine safety.

Acknowledgement

The authors would like to acknowledge the effort of the team from Vantage Interactive who have helped in the development of these modules. The team was originally a part of UNSW's School of Mining Engineering before the development of this spin off company. The authors would also like to thank New South Innovations (NSi) for their continuous support in these projects.

REFERENCES


