Working in the Classroom – A Vision of Miner Training in the 21st Century

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ABSTRACT

The changing demographics of the mining industry make successful passing of knowledge and skills to the next generation critical. Training methods and technologies are being developed to meet this need. Twenty years ago classroom training was largely a one-way transfer of knowledge through instructor lectures. In contrast, instructors today can use virtual reality technologies to guide trainees as they fully participate in learning experiences. Trainees can interact with the virtual work environment, co-workers, and equipment without being exposed to workplace hazards. The speed of advancement in mine safety, health, and production training shows no sign of slowing in the next 20 years. Researchers at the National Institute for Occupational Safety and Health have studied and participated in the evolution of miner training. A look at training materials they have created in the past and those they are currently developing reveals changes in methods and technologies over time and also key characteristics which have remained constant. Possibilities for the future can be discussed in the framework of an implementation of virtual reality in new miner training sessions. The example computer-based training package teaches new miners to read mine maps and provides opportunity to practice navigation skills in a virtual mine. With this 'serious game', trainees experience the look and feel of moving through an underground coal mine while in the safety of their classroom. During field-testing in 2007, trainees and instructors responded very favourably to this new way of learning. The software was usable by mine trainers with even limited computer expertise and could be installed on the affordable computers they were using for their more traditional slide presentations. The Underground Coal Mine Map Reading Training's foundation on past successful development strategies and its acceptance by today's instructors and trainees provide valuable lessons for developing training materials, strategies, and technologies for mining's future.

INTRODUCTION

Workforce demographics are changing in many parts of the world. Extended healthy life-spans, lower birth-rates, and the impact of the baby-boomer cohort have led to ageing populations. In the United States, the age of the mining workforce is even higher than that of the general population (Bureau of Labour Statistics, 2007). So what does that mean for mine training? Today's mining industry is running on the knowledge and skills of experienced workers. They know their jobs. They may have worked in multiple positions through their careers. They are leaders with solid backgrounds and expertise. But in the next 20 years, many of those experienced miners will leave the industry. Even if they delay retirement, as many baby-boomers report they plan to do, they will eventually move on. Will those left be prepared to meet 21st century challenges? Moving forward with training research and development is vital to preparing for the industry's impending changing of the guard.

The 21st century workforce will not look the same as last century's workers. Using technology is a normal part of daily life for them. Even those not highly educated have knowledge about and often skill with computers or video game consoles:

> *Survey studies suggest that game experiences are changing a generation's attitudes toward work and learning* (Squire, 2006).

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They also like to multi-task and can take in large quantities of information at one time. These qualities should be exploited by mine trainers. On the other hand, some have said this new generation of workers is impatient with information not given in sound bite quantities. If true, this could create a potential lack of depth in understanding that must be considered when planning training.

Unlike the workforce, the 21st century training room often looks very much like it did 50 or more years ago. Instructors standing at the front of the room lecture to students sitting at desks or tables. The expert instructor introduces job-related concepts and techniques and tells about his or her experiences. In a nod to newer technology, the information may be relayed from experts via video. In both cases, trainees are the recipients of knowledge. They will test the concepts and try their skills when they enter the workplace and face a related task. That circumstance may be just after training or it can be months or even years later. This is not the optimal way to prepare miners. New training philosophies, tools, and techniques must be brought to the mine classroom.

Computer-based virtual reality technologies offer one avenue for updating training. The following discussion will cover how narrative-based training has evolved and is likely to continue changing in the future. The Underground Coal Mine Map Reading Training (UCMMRT) developed by the National Institute for Occupational Safety and Health (NIOSH) is provided as a current example. Training for emergency response using this technology is also introduced. An additional comment is made on the future of serious games and how related changes might impact training in the mining industry.

THE EVOLUTION OF TRAINING

Teaching in the mid and late 1900s was widely considered an information transfer task:

> *The learning process was typically thought to consist of a knowledgeable educator who constructed and transmitted knowledge on a particular topic to learners using the accepted instructional technologies of the day – books, articles, and lectures* (Ruben, 1999).

The goal was to pass information from teacher to learner. If the learner could recall the information imparted by the instructor and communicate it back through a standardised written test, he or she was seen as successful. While these teaching and assessment philosophies and related methods are not uncommon today, other options are a better fit with the workforce of the future:

> *Much of the current literature on contemporary pedagogy advises that to best prepare 21st century learners for the increasingly complex and interconnected global society in which they live and work, institutions should implement, across all disciplines, pedagogical practices that involve interactive, inquiry- or problem-based, technology-enriched teaching and learning* (Moore, Fowler and Watson, 2007).

Formal education and training of the past focused on knowing. Newer methods add a skills or doing component. Trainees can no longer be successful by reciting back what an instructor has said. Instead, trainees must understand the context in which the information can be used. In the mining workplace, they are also often called upon to work or communicate with other people. Training that takes into account the physical and social environment in which a job must be performed is more complex than that which leads to the recall of facts. This is a simplification of the evolution of training, but generally the movement has been from fact-based lecture and reading toward more context-based methods. One way to provide context is to develop training in a narrative framework. Narrative-based techniques such as guided group discussions, table-top simulations, and interactive computer-based exercises force trainees to metaphorically leave their seats and participate in learning.

The use of narrative is nothing new to education and training. Even prehistoric storytellers used this method. Stories heard or read immerse the learner in the setting as planned by the storyteller:

> *A stirring narrative in any medium can be experienced as a virtual reality because our brains are programmed to tune into stories with an intensity that can obliterate the world around us* (Murray, 1997).

Mine trainers have long told stories to impart warnings or guidance. But they did not always develop their narratives to meet specific training objectives or standardise them so the same message could be given during multiple training sessions. Formal scenario building makes storytelling more effective as a training medium.

Technological advances are making narrative training easier to create and deliver. The widespread use of video games has led trainees to not only accept, but expect high-tech professional quality computer-based training:

> *Many of today's youth spend more time playing in digital worlds than they do watching television, reading, or watching films* (Squire 2006).

This is an exciting reality for mine training as it means computers can be used to generate contexts for narrative training. Learning in context happens as trainees take roles in the story and virtually have an experience. Rather than reading, watching a film, or hearing about a place, trainees can explore and interact:

> *The success of complex games demonstrates that they can teach higher-order thinking skills such as strategic thinking, interpretative analysis, problem solving, plan formulations and execution, and adaptation to rapid change* (Federation of American Scientists, 2006).

Training on these types of skills will engage trainees and better prepare them for 21st century mining workplaces.

CREATING NARRATIVE-BASED TRAINING

Researchers at the National Institute for Occupational Safety and Health (NIOSH) have been developing and assessing narrative-based training since the 1980s. Early studies were published under the agency name the Bureau of Mines. Much of this early work was done in conjunction with faculty, staff, and students at the University of Kentucky (Cole *et al,* 2001). Training for non-routine skills was based on actual accident and injury reports (for examples, see the list of 'Training Exercises' at the NIOSH web page: http://www.cdc.gov/niosh/mining/products). Rather than relaying stories of given events, training objectives were defined for a specific subject and then a story was constructed by taking experiences and contexts from multiple events that could best meet those objectives. Drawings and maps were the only visuals provided, but the realism of the stories immersed the trainees who imagined themselves as part of the constructed tale. The stories were presented in segments with questions given to trainees at critical decision points. Trainees were given immediate feedback to their responses that explained why their choices were correct or incorrect and moved the storyline along. The training was successful because it relied on compelling narratives set in contexts that were believable and familiar to trainees. Cognitively the training was realistic, but without today's availability of computer graphical and interactive capabilities trainees were left to imagine the settings.

Current training research and development at NIOSH is built on these early simulations but uses technology to add realistic visual and auditory cues. Video game-inspired models of equipment, environments, and people are being created. Trainees can now 'live' the story in a virtual mine. A multi-disciplinary team at NIOSH has created and tested the Underground Coal Mine Map Reading Training (UCMMRT) with new recruits. The team used various software packages to model people and things and a video game engine to build a virtual mine environment where new miners can safely practice map reading and mine navigation skills. See Figure 1 for an example screen shot. Through the development and testing process, the team learned lessons which can inform future training development efforts.

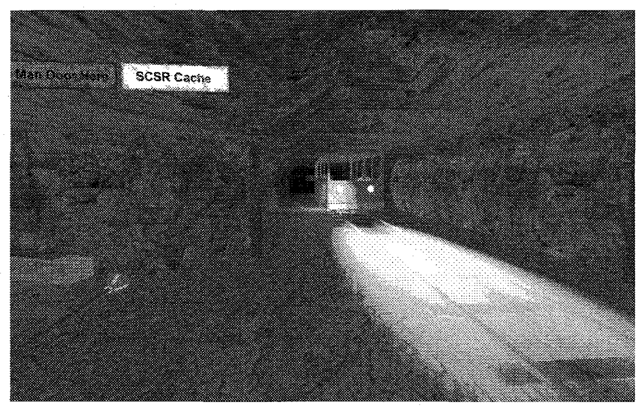

FIG 1 - Screen shot of virtual mine environment.

UNDERGROUND COAL MINE MAP READING SKILLS TRAINING

To the uninitiated an underground mine can be a dark, complex maze. When travelling through mine passages (ie entries and cross-cuts), they encounter dead ends (stoppings), unending obstacles (ie beltlines), and seemingly random unusual pieces of equipment. Given the complexity of mine navigation, and that many new employees have spent little time in an underground coal mine, the potential exists for lost miners to get themselves in dangerous situations. In the United States, new miners are required to take at least 40 hours of training before starting work. They are taught terminology, basic concepts and how to work safely. Traditionally much of this training takes place in a classroom. The timing and extent of the in-mine portion of the training varies widely and trainees are likely to be overwhelmed with new information as they try to tie the classroom training to the actual mine environment.

NIOSH researchers have created training materials to help familiarise trainees with the environment and navigation techniques before they enter the real mine. The training software consists of two computer-based segments. The first, Map Reading Basics, covers terms and concepts that trainees need to know in order to understand the mine and where miners can and cannot travel. The new miners then 'enter' a virtual mine, while still safely in their classroom, to test their new knowledge and skills. The Mine Navigation Challenge was built using a first person shooter computer game engine. This type of 'serious game' allows trainees to 'walk' through the mine with a computer mouse and/or keyboard commands. They participate in the story as they are given tasks requiring them to find specific locations on a paper mine map and navigate to those locations in the virtual mine. Virtual miners encountered along the way give information and further directions. To successfully complete the tasks, trainees count cross-cuts, go through man doors, and find belt crossovers. There are two main locations the trainees must find with the second being more difficult to locate. After completing the training, more practice can be gained in a scavenger hunt module where trainees attempt to find objects located around the virtual mine.

The UCMMRT was tested in new miner classes at three training locations as it was being developed. Participants in these formative evaluations ranged in age from 18 to 54 years with a median age of 30. A few more experienced miners returning to the industry after an absence were included, but 93.4 per cent had less than one year of mining experience. Thirty-four per cent of them play computer games as least once a week, but 35 per cent report never playing them.

Trainees overwhelmingly liked the training with 99 per cent of the 135 new miners responding yes when asked if they enjoyed the session. They were also asked if they would like future training to include computer-based sessions and 92 per cent said they would. These high marks were given in spite of the fact that the training was conducted in less than ideal conditions. During the training sessions groups of trainees (five to 25 trainees) participated as the virtual mine was projected on a screen in the front of the room. The quality of the projected images often suffered as a result of ambient room light from sources such as windows or room lights that could not be dimmed. Projection systems currently available provide higher lumen output and contrast ratios that can alleviate this problem. In small classes it might be possible to have each trainee or small group at an individual computer station. The trainees will get a more immersive experience if they are controlling the simulation. However, during the testing, trainees discussed and decided where they should go and then the instructor or one of the trainees operated the keyboard and mouse. The sessions were chaotic at times, but the seasoned instructors who ran the tests successfully guided the groups and were happy with the outcomes.

Trainees were asked what they liked best about the UCMMRT session. A response related to the realism of the training was given by 52 per cent of the trainees. They wrote responses like:

> *It was realistic and interesting. It felt like you were the one in the simulator.*
>
> *Gave a hands-on type feel to what was explained. A picture is worth a thousand words. Also answered a lot of questions that words cannot explain. Doing something instead of talking about it is much more helpful and worth the time.*

The next most common response, at 23 per cent, was related to engagement with comments such as:

> *I liked that it was really hands-on and had to make you think as you were walking along.*

Five per cent of respondents said the part they liked best was being lost:

> *It gave me an idea what to expect and look for when lost.*

In other words, they liked being part of a narrative that was created by their decisions. When asked what they did not like about the training, 41 per cent wrote in that they didn't have any negative comments. An example of a response is:

> *Thought it was great!!*

Nine per cent responded that it should have been more challenging with comments like:

> *It didn't last long enough. I would have liked to have more time with the virtual mine exercises.*

In the after-action review, trainees were shown the route they had selected (generated by a feature in the training software and shown in Figure 2) and discussed where decisions had helped or hurt them in reaching their goal. In this context, map reading concepts became more than words – they had real application.

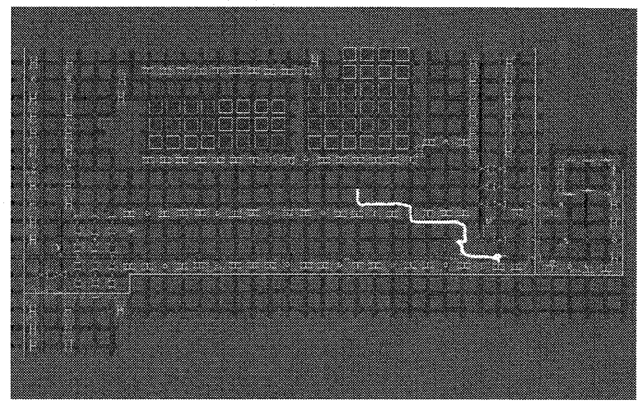

FIG 2 - Overhead view of route taken for after-action review.

VIRTUAL REALITY TRAINING EXPERIENCES

Virtual reality technologies allow trainees to engage in learning in ways impossible with more passive methods. Taking roles in stories where decisions impact the outcome of events requires a deeper understanding of concepts than does repeating definitions:

> *Learning through experience is a powerful approach when combined with today's advanced learning technologies* (Menaker *et al*, 2006).

But just building a virtual mine, or any simulated environment, and allowing trainees to 'walk' through it will not result in optimal training. Trainees are likely to explore and become more familiar with a mine environment with an unguided walk-through, but more complex training goals require more structured use of virtual reality tools:

> *Experience alone may not be an effective or efficient strategy for developing the knowledge and skills, including adaptive thinking, problem solving, and decision making ...* (Menaker *et al*, 2006).

Instead, training must include the application of knowledge and skills in context. Narrative training set in computer generated environments provides an excellent platform for learning and practicing higher order thinking skills.

Instructional developers can create experiences that deliberately move through certain learning and practicing steps. One way to structure experiential learning is listed below (Menaker *et al*, 2006). The examples provided for each are from the UCMMRT:

- *Engage the learner mentally* – the trainee is introduced to the environment while riding a vehicle to the working area.
- *Emulate real-world requirements. Real-world refers to the physical environment and the cognitive tasks* – the trainee is told to take tools to the boss who is doing work at a specified location. The trainee must use a paper map to navigate to that location.

- *Allow the learner to experience effects of decisions. Effects can be naturally occurring ... or delivered by an instructional agent ...* – the trainee can become lost and must find naturally occurring cues (such as survey station markers) to get back to a known location. If trainees go too far away from the appropriate route a virtual miner will tell them not to go further in that direction.
- *Require the learner to reflect on outcomes of their actions* – a map is provided for the after action review with the trainee's route displayed. Trainees can see where they made correct or incorrect choices.
- *Revisit experiences, increasing complexity of experiences to expand learners' knowledge and skills by increasing number of events, pacing and emotional intensity* – there are two main tasks in the Mine Navigation Training, with fewer environmental cues for navigation provided in the area of the second task.

Purposely guiding trainees through a virtual environment and requiring that they make certain decisions in order to progress creates an experience that meets specified learning objectives and is repeatable during future training sessions. Video game technologies facilitate creation of this type of training:

> *While there are numerous claims that games can be applied to learning, relatively few attempts can be found where principles of pedagogy were explicitly followed a priori in design* (Federation of American Scientists, 2006).

A key to proper use of virtual reality technologies in future training is defining explicit learning objectives and how they will be achieved.

PHYSICAL AND COGNITIVE FIDELITY IN VIRTUAL REALITY TRAINING

Determining how real is real enough is a question that should be explored early in the development of a training package. Advances in hardware and software allow extremely realistic rendering of objects and environments, but creation of such environments and equipment to display the created models come at a cost, and the physical world is only one part of the equation. Cognitive reality, which is related to how believable the story is to the trainee, must also be considered:

> *We fear that the pendulum has swung to the physical fidelity because technology enables us to create more realistic environments, often at the expense of the cognitive fidelity and reflection aspects of design ... As trends emerge and clients insist on the most up-to-date strategies and whiz-bang effects, instructional designers must ensure that design provides the essential instructional elements to support their superficial appeal* (Menaker *et al*, 2006).

The multi-disciplinary team that developed the map reading training grappled with fidelity issues throughout the development process. Giving an appropriate look and feel to the mine environment was important as the product was to be used to teach naive trainees about that environment. It did not, however, have to be correct in aspects unrelated to mine navigation. For example, self-contained self-rescuer (SCSR) caches could be used as a navigational cue, so boxes marked SCSR Cache were placed in appropriate places in the virtual mine. The use of SCSRs were not required for these training objectives, so resources were not spent modelling cache boxes that could be opened and SCSRs that could be seen in them. Cognitive fidelity was achieved by giving the trainee a relatively simple task that required going to locations where miners would reasonably be working. One location was near a fall where miners were doing clean up and support and another was where a stopping was being built. Resources were not used to create a storyline involving the face area of the mine as it would have required much more artwork with limited gain toward meeting the training objectives.

The physical fidelity of virtual reality training will continue to improve in the future. The map reading training software can be run on a modestly powered laptop. Tests have found that:

> *... higher-fidelity graphics served to focus (trainees') attention initially* (Raths, 2006).

These same tests found that the graphics:

> *... were less important than other attributes for sustaining (trainees') attention for longer periods of time* (Raths, 2006).

This is when questions of cognitive fidelity arise. Cognitive fidelity requires the same processes that were followed to create the narrative training of the past. Good storytellers who can tie actual or likely events to key training objectives are the starting point. The new twist is that new computer technologies let trainees interact with and modify the story. How this will change the way narrative training is created is yet to be defined. In the end, both types of fidelity are important and the development team must determine how much is enough.

INSTRUCTORS AND VIRTUAL REALITY TRAINING

Another issue which impacts training design and resource requirements is the decision whether instructors will be used to lead training sessions. When training is designed so that a trainee interacts with the computer without an instructor, the logistics of training delivery can be simplified. Training can take place at times and locations convenient for trainees and their work schedules. Multiple trainees, in various locations, can receive exactly the same training materials, move through the session at their own pace and cover materials in a depth that matches their training needs. Instructor scheduling and salary are not required. More resources are, however, required to develop this type of training. All information to be conveyed during training must come from the program. It must be complex and detailed enough to explain how to access the content and use the program without instructor help. A system is needed to assist with technical problems and answer trainee questions. The extensiveness of software and content assistance will vary based on the composition of the trainee audience. But in general, more programming resources will be needed to create materials that are not designed to be delivered by a trainer.

The appropriateness of introducing content without instructors available will vary based on the sophistication of the audience and the complexity of the material being covered. Instructor-led scenario sessions can take a variety of formats. Trainees may interact with individual computers, or a group may use one computer and interact with the simulation together. Instructor-led simulations can be less detailed than those designed to be run without an instructor, but this requires a skilled instructor to facilitate the session and an instructor's guide to prepare and assist this leader. The limited research available on this topic suggests that instructor-led may be more effective training:

> *We are confident that training with games is more effective when qualified instructors are present to guide leader behavior by offering coaching and feedback, evaluating performance, and conducting after action reviews that require (trainees) to think critically about their actions and decisions* (Beal, 2005).

Training materials designed for instructor-led sessions may be less resource-intensive during development, but require scheduling and paying for the time and sometimes travel costs for instructors and trainees.

When developing the UCMMRT, the NIOSH team determined that it may be used in instructor-led sessions or by individual trainees. To meet the needs of individual trainees, detailed instructions for moving through the material was included and sources for additional information provided. Because of common training structures and computer equipment availability, the team knew that the program was likely to be used by instructors who would guide their classes through the material using laptop computers and projection units. An instructor's guide was written to assist trainers as they lead these types of sessions. The majority of developmental testing of the training package was done under this condition. Instructors reported that the materials worked well for them in their classrooms.

MODELLING AN UNDERGROUND COAL MINE

For this scenario, a five-entry submains was created with a track and beltline. Trainee interaction with the mine environment and non-player characters is limited as the objectives do not require it. Non-player characters give instructions, doors can be opened and closed, and a vehicle can be ridden through one area of the mine. Otherwise, the trainee is simply walking through the environment.

The creation of non-player miner characters and some animations was contracted out to SimOps Studios, Inc, (http://www.simopsstudios.com), which worked closely with the project team. One of the characters can be seen in Figure 3. Even though interaction was limited for this training application, the NIOSH team plans to consider more intensive interaction between player and the virtual world in a future training scenario. In that scenario, players will interact not only with objects but also non-character players:

> *Although creating technical simulations is fairly straightforward, such as how to fly an airplane, it's more difficult to simulate realistic social situations. After reaching technical proficiency in any job, an employee reaches a plateau where change in job performance is a function of his or her ability to interact with others in social situations* (Kindley, 2002).

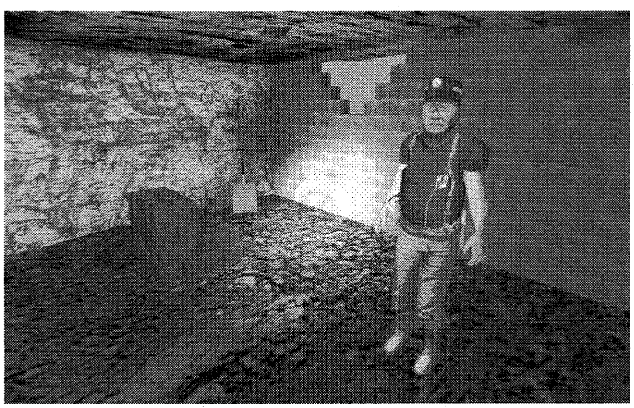

FIG 3 - Non-player character.

The NIOSH team's next scenario will require such interactions and use virtual miners who behave as realistically as possible given available resources:

> *To be effective, intelligent agents need to portray emotions, demonstrate actions that show thought processes, and behave realistically* (Federation of American Scientists, 2006).

EMERGENCY EVACUATION TRAINING SCENARIO

The next NIOSH serious game will focus on knowledge and skills needed to evacuate a mine during an emergency. The narrative will be based on past NIOSH research in the area of human behaviour during mine emergencies. The same mine area used for the UCMMRT will be used for this new program. Components that will allow the 'emergency' to take place in the mine will be built on past NIOSH work on developing such a virtual environment. The key enhancements in this new package are as follows:

- A multi-player option allows multiple trainees to enter the virtual mine at the same time via networked computers. Communication between trainees will be available.
- Communication with non-player characters will be enhanced.
- Face equipment has been modelled and added to the virtual mine.
- The beltline can be stopped by trainees.
- A ventilation model will provide realistic mine ventilation data for creation of realistic readings and air movement.
- Simulated smoke will move through the mine based on ventilation model data.
- SCSRs can be picked up, put down, and donned by players.
- Gas readings can be taken.
- Lifelines and tether lines can be used.
- A refuge chamber is available (see Figure 4).

FIG 4 - Player avatars standing in smoke at refuge chamber.

This training scenario is not complete as this document is being written but is anticipated to be in testing by September 2008. A draft will be ready for viewing at the Future Mining Conference in November 2008.

EVALUATING VIRTUAL MINES FOR TRAINING

At this point in time, research is limited on the effectiveness of serious games for training. The United States military is convinced of its value, as shown by their large investment in this technology. Much of the military work, however, is not published or accessible to other researchers. Private firms that create serious games also do not publicly release evaluations of their products. 'Academic research on simulation should continue', Sachdeva (director of the education division of the American College of Surgeons in Chicago) says:

> *... but the lack of data should not slow us down. When airlines started using simulation as standard operating procedure, they didn't have controlled studies that proved its effectiveness. Some things you just have to refer to expert judgment even if you can't have conclusive proof* (Raths, 2006).

Future evaluations of computer-based scenarios for training miners should be conducted. But simple knowledge tests will not be sufficient to assess the complex thinking skills that are the focus of this type of training. For each training package, specific learning and performance goals must be defined and appropriate evaluation methods created. This is no small task and will require creative evaluation strategies to be developed. As was said during a recent presentation by an instructor who trains military medics, we are using 'first-person shooters' to create 'first-person thinkers' (Cassidy, 2008). How will thinking be operationalised so improvement can be gauged? One possible solution is to develop evaluation tools that are embedded in the training software.

FUTURE TRENDS IN SERIOUS GAMING

As new game engine software is developed, companies often make older versions of their programs available at little or no cost. Examining the current trends in the entertainment gaming industry yields a glimpse of what technologies will soon be available to developers of the next generation of serious games for training future miners. Three areas warrant examination: virtual environment (VE) complexity, non-player character (NPC) artificial intelligence, and computer hardware trends.

The game engines currently available, such as Epic's Unreal Engine3 and id Software's id tech4, allow players to interact with the environment in a much more dynamic way than in previous game engines. In older games some items could be moved about the VE at the player's will. In the current systems the VE itself can be modified by the player in real-time, for example; walls can be torn down (if the player has the proper equipment – usually a weapon of some sort). The interaction with these enhanced VEs also benefit from another trend in gaming hardware; dedicated physics processing cards. Many of the current game titles employ some type of realistic physics simulation. Objects fall and bounce according to 'real-world' equations of motion. These calculations are taxing on the system, so having a dedicated processor allows special effects with many more objects bouncing around the environment. Translated into a miner training simulation this would allow scenario authors the ability to create more realistic explosions or roof falls, belts moving material such as coal, or ventilation pushing smoke throughout the virtual environment.

As virtual characters become more realistic visually, game developers are also developing more advanced artificial intelligence software to allow more complex and realistic behaviour for the NPCs. An example of this is in Star Wars game Force Unleashed (http://www.lucasarts.com/games/theforceunleashed/), due for release in the fall of 2008. This software combines environmental complexity with dynamic elements and adds sophisticated behaviour algorithms to the non-player characters that allow them to respond to changes in the environment and game play in a much more realistic fashion. The NPCs have a self-preservation sense that causes them to avoid hazards in the virtual world, even as that environment is changing. The added realism of complex NPC behaviour draws the human participant into the simulation, enhancing the experiential aspects of the game play or training.

Computer hardware continues to make technological leaps. Displays and graphics cards now offer nearly photorealistic resolution and fidelity of virtual environments in real-time. The expense of increasingly large displays continues to drop as more of this technology makes its way to the mass-market. Stereoscopic versions of these displays are also being developed, providing additional immersion for future trainees. It remains to be seen whether dedicated physics processors (or for that matter dedicated graphics cards) will still be the norm given the trend toward multiprocessor computers. Whatever the implementation, the likely result is increasingly realistic virtual mines that can be used for training.

CONCLUSIONS

The use of serious games for training is just starting in the mining industry. Initial indications are that it will be embraced by most trainers and trainees in the future, but it will not be accepted by everyone:

> *Not all contemporary students are eager to have faculty disrupt known approaches to teaching, even the 'stuff and dump' learning that even they criticise, to become critically engaged, self-reflexive, sophisticated problem-solvers and producers of knowledge* (Moore, Fowler and Watson, 2007).

And like these trainees, some instructors prefer to stick to their tried and tested methods. But for those willing to step out and try something new, virtual mines open up a world of training possibilities. How computer technology will be used to bring mines into the classroom of the 21st century remains to be seen. The technology will advance, computer equipment will become more available, and miners and trainers will be more comfortable using them:

> *Research has demonstrated that simulation environments are powerful learning tools that encourage exploration by allowing learners to manipulate parameters and visualise results. Simulation-based learning environments can also provide 'anchored' or situated learning environments that can help learners understand the types of problems and opportunities that real experts confront and how they use their knowledge to solve those problems* (Federation of American Scientists, 2006).

The potential for miners 'working' in the safety of the classroom as they learn mine knowledge and skills is limited only by the creative thinking of industry leaders and the resources put toward research and development.

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