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Shiva Pedram
University of Wollongong

Pascal Perez
University of Wollongong

Stephen Palmisano
University of Wollongong

Matthew Farrelly
Coal Services

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A SYSTEMATIC APPROACH TO EVALUATE THE ROLE OF VIRTUAL REALITY AS A SAFETY TRAINING TOOL IN THE CONTEXT OF THE MINING INDUSTRY

Shiva Pedram[1], Pascal Perez[1], Stephen Palmisano[2] and Matthew Farrelly[3]

ABSTRACT: The Australian mining industry has achieved impressive performance and safety results through continuous improvement of its training standards. Interactive virtual reality-based training is the most recent technology used to enhance workers' competencies in a safe and controlled environment which allows the replicable testing of extreme event scenarios. Like any other training method, Virtual reality (VR) -based training must be assessed in order to evaluate the advantages and limitations of this innovative technology, compared with more traditional approaches. Research was aimed at designing and implementing a framework to tackle the cultural issues involved in accepting innovative VR-based training programs developed for high risk industries. The present study was conducted with Coal Services Pty Ltd, a pioneering training provider for the coal mining industry in NSW, Australia. The research focussed on specific training programs developed for the mine rescue brigades. These brigade teams are made up of highly specialized miner volunteers who provide the primary response to major incidents. The research framework examined the adequacy of training needs, technological capabilities and the implementation of interactive simulation. The research outcomes provide evidence-based information on the advantages and limitations of VR-based training for mining rescue brigades. The framework is flexible and can be applied to other types of training for the mining industry or adapted for use in other industries.

INTRODUCTION

Computer simulation as a learning environment has progressively embraced technological innovations ranging from chart-based interfaces to fully immersive environments. (Bell *et al.,* 1990 and Jou and Wang 2012). Virtual Reality (VR) provides both immersive and interactive features, allowing users to 'feel' that they are actually in the training environment (Raskind *et al.,* 2005). Best practice in the mining industry includes extensive initial and professional training for staff involved in field operations. Simulator-based training is now frequently used to both establish and maintain this training. A VR environment, which is an interactive 3-D representation of the mine, has a high potential to enhance miners' safety through improved techniques for training, retraining and up-skilling.

During an emergency, rescue brigades are the first teams responding to a mining incident. Their members are highly skilled volunteers, selected by mine managers at each production pit. Rescue brigades attend frequent training sessions in order to perform effectively in an emergency situation. A VR-based training program for rescue brigades provides a safe environment to perform collective drills for various emergency scenarios. During these sessions, trainees can improve their technical and non-technical skills. Previous research has shown that flight simulators are very successful at bringing learning and theory into practice in a supervised, safe but highly realistic environment (Deaton *et al.,* 2005). Despite the rapid development of VR-based training in the mining industry there has been little (if any) formal evaluation of its impact on miner's skills and competencies. Furthermore, due to the specificity of underground mining, it would be dangerously misleading to extrapolate training transfer results from other industries such as aeronautics and automotive.

[1] *SMART Infrastructure Facility, University of Wollongong, Email: spedram@uow.edu.au, Tel: 0432509790,*
[2] *Associate Professor, Faculty of Social science, University of Wollongong,*
[3] *Coal Services , Woonona, NSW, 2517, Email: matthew.farrelly@coalservices.com.au,*

Hence, we describe in this paper an experimental design aimed at introducing a systematic framework to better understand and evaluate VR-based training programs. In this study we conducted the research on VR-based training developed by Coal Services Ltd for underground rescue brigades in NSW, Australia.

Why do Accidents Happen?

Historically the mining industry is one of the most hazardous industrial sectors. Although the industry has achieved significant success in reducing the number of accidents and limiting their consequences, it remains a risky business. According to NSW Trade and Investment, the average Fatal Injury Frequency Rate (FIFR) decreased by 65% between 2007 and 2012. The overall Lost Time Injury Frequency Rate (LTIFR) also decreased by 58% over the same period while the serious bodily injury frequency rate (SBIFR) decreased by 56% (Trade and Investment Resources and Energy, 2013). These records suggest that the Australian mining industry has achieved remarkable improvements through continuous development of its safety procedures. The bulk of the remaining accidents appear to be due to human error, as has been shown by Williamson (1990) in Australia and in the US. Sources of human errors are diverse and need to be integrated into relevant training programs.

The 'Human Factor Analysis and Classification System' (HFACS) is a systematic and evidence-based framework aimed to design, assess and enhance the interaction between individuals, technologies (including equipment) and the organisation (Wiegmann and Shappell, 2001). HFACS describes human error at each of four levels of failure: 1) unsafe acts of operators, 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences and outside factors (Patterson and Shappell 2010). HFACS has been implemented in various hazardous industries such as civil aviation ((Wiegmann and Shappell 2001; Wiegmann *et al.,* 2005 and Shappell *et al.,* 2007), air traffic control (Broach and Dollar 2002), logistics (Reinach and Viale 2006 and Baysari *et al.,* 2008 and Celik and Cebi 2009), and medicine (El Bardissi *et al.,* 2007).

According to the HFACS framework (Figure 1), human errors should be minimised if appropriate training programs have been put in to the place.

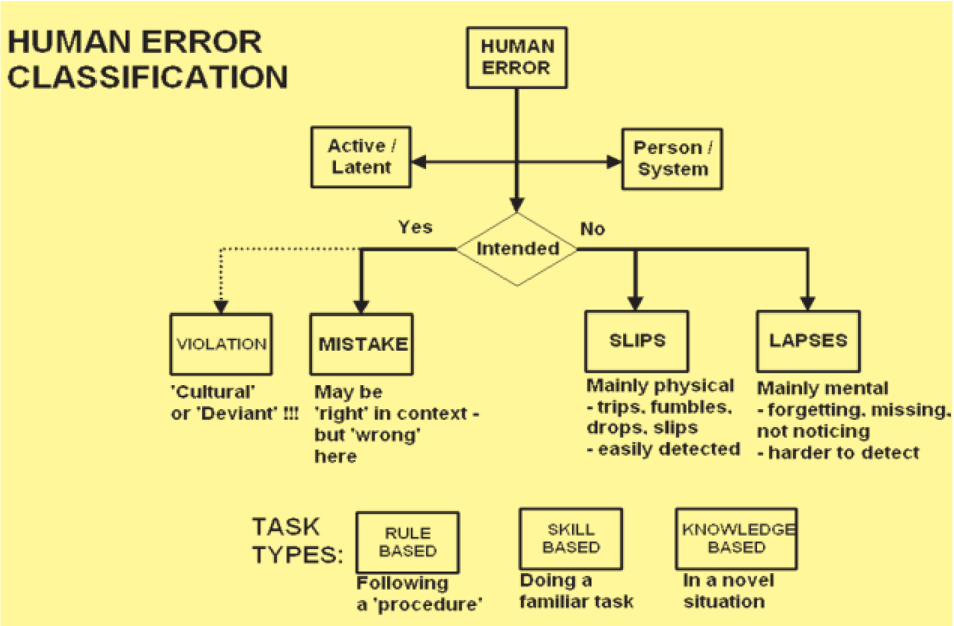

Figure 1: Human Error Classification (Trade and Investment 2013)

VR-based Training for Rescue Brigades

Misanchuk (1984) lists the three main factors used to evaluate the quality of a training session or program: (1) the employee's ability to accomplish the assigned task, (2) the relevance of the training materials to what trainees are expected to do, and (3) the employee's motivation to undertake training. Oftentimes, this technique of evaluation works however the case is different if we are aiming at measuring safety outcomes. Therefore, we cannot measure and evaluate the success of training through its impact directly on the quality of workers. Figure 2 shows how Coal Services Pty Ltd is developing the content for VR training sessions and how they are aiming to measure the training outcomes through the annual underground coal mine competitions.

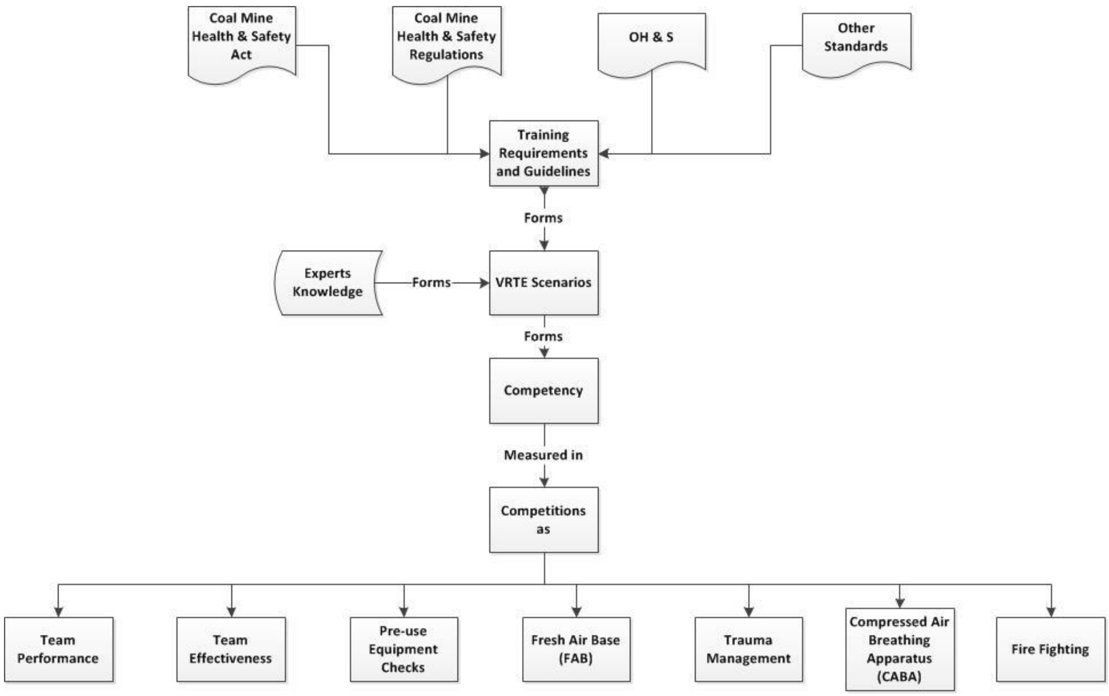

Figure 2: Training Scenario Development and Evaluation

Training requirements and guidelines are based on Australian Coal Mine Health and Safety Acts and regulations. Hence, training transfer can be evaluated against the following team performance, team effectiveness, pre-use equipment checks, fresh-air base, trauma management, use of the compressed air breathing apparatus and fire-fighting skills.

However, it must be mentioned that the rescue brigades undergo through six rounds of different training each year. As only one of these training modules is conducted in VR, it is not straight forward to determine the actual contribution of VR training to performance. Currently ambiguity exists as to whether VR is actually a successful training tool and if it is responsible for significant changes to the expected safety training outcomes.

In the next section a systematic approach is proposed which should enable industry to investigate and clarify the role of V R as a training tool (i.e. to determine whether it will fulfil the training requirements and identify its shortcomings). This approach: (1) identifies the specific training needs, (2) identifies any issues that will be faced if they choose the "real life training approach" and (3) informs them what the VR's capabilities are and what are users' opinion on its identified capabilities.

Participants

This study includes 280 Brigades men who were experienced underground miners and voluntarily joined the mine rescue brigades. We chose this group of miners since we could do a follow up study on them and monitor their performance in real life. With the other groups the chances were low that we would be able to monitor their performance in future: e.g. there are unemployed miners who attend the induction training courses at Coal Services to be prepared for future employment, since there is no guarantee when they are going to be employed, they were excluded them from this study and only focussed on rescue brigades who are currently employed and in case of emergencies will be deployed. Moreover, VR development team and trainers (10 trainers) have been interviewed.

FRAMEWORK

The framework (Figure 3) includes four nested layers of analysis. Gaps and mismatches at the interface between two layers will help to identify training deficiencies and possible improvements to the current programs set up by the industry.

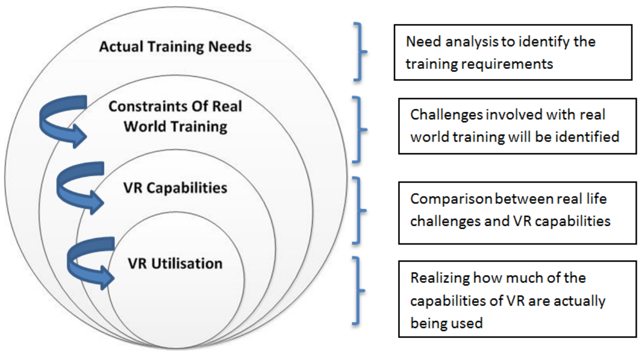

Figure 3: Evaluation framework

The outermost layer of the framework corresponds to actual training needs. Interviews with trainers, mine managers and station managers constitute the main source of information alongside reviews of the literature produced by the mining industry. The second layer focuses on constraints associated with real-world training (aka traditional training). The third layer focusses on capabilities associated with VR technology. In-depth interviews with VR designers will help to better understand potential and actual use of this technology. Finally, the innermost layer corresponds to the learning process experienced by trainees. Over a two-year period, several rescue brigades have been followed through their training programs, focussing on VR-based training sessions.

Actual training needs

Need analysis is required to first identify the users' needs, and then assess the need to recognize the importance and relevance of the identified problem and solution. Need is defined as a problem of the target group which can be solved (McKillip 1987). Based on McKillip (1987) there are five main steps in need analysis: identifying the users and uses, describing target population, need identification, need assessment and finally communicating the results to the decision maker and other relevant stakeholders.

Training Need analysis starts with two questions (1) is the training tool adequate or not? And (2) if it is inadequate what can correct it? Subject Matter Experts (SMEs), such as trainers and mine managers, were interviewed to identify potential training needs and how those needs could be fulfilled (Figure 4).

Real-world's training constraints

Focus groups, made up of SMEs, trainees and trainers were asked to identify: (1) the constraints associated with real-world training, and (2) the potential for VR-based training to overcome these limitations.

VR-based training capabilities

Based on the above, an initial set of desirable VR-based training features can be identified. Interviews with VR designers and trainers identified: (1) the current capabilities of VRs, (2) the limitations of VR and potential for upgrade, and (3) the relevance of VR technology features for training purposes. The objective was to identify: (1) the role of simulation features and resources in overcoming the identified training challenges, and (2) the challenges of using each simulation feature. The VR-based training environment used by coal services Ltd corresponds to a state-of-the-art 360° interactive theatre with 3-D immersive visualization.

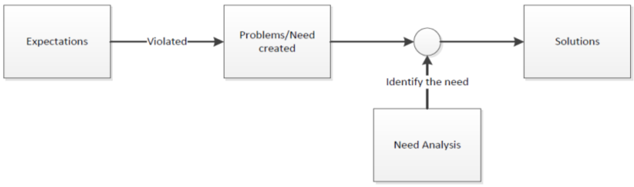

Figure 4: Need Analysis Framework

VR-based training utilisation

Over a two-year period, several rescue brigades were followed through their training programs across four training facilities (Wollongong, Newcastle, Singleton and Lithgow in NSW). Each trainee had to complete a short questionnaire before and after each training session in order to record previous experiences, expectations, responses to VR environments and self-assessment of individual performance. Equivalent questionnaires were provided to the trainers as well.

RESULTS

Actual training needs from trainees point of view

It is crucial to identify what are the characteristics of a successful training tool/environment from different points of views in order to be able to compare it to alternative tools/environments (to determine what features are missing or need to be added or modified).

Table 1: Training Needs from Trainees Point of View

Training Needs from Trainees Point of View	
1.	**Recreate the Real Conditions (such as smell, noise, temperature, dusk**
2.	**Physical Activities can be done**
3.	**Accessible at any time training is needed**
4.	**Faithfully recreate various real life scenarios**
5.	**All the mines can be seen and experienced**
6.	**Experiencing the hazard and danger**
7.	**Minimum of distraction to the training process**
8.	**Safe training environment**

Real-world's training constraints

Trainees were asked to identify the constraints they thought were associated with conducting training at actual mine sites. They indicated that training in the pit felt more realistic, however, they mentioned that there were some challenges which would affect training and ultimately learning outcomes. The table below summarises the reported constraints of real-world training:

Table 2: Real-World's Training Constraints from Trainees point of view

	Real-World's Training Constraints from Trainees point of view
1.	Pit training is realistic and physically too active
2.	Pit training requires access and consent from mine operators
3.	Pit training has logistical issues and time constraints
4.	Pit training has less variety in scenarios/content
5.	Pit training is not safe (It is higher risk, potentially hazardous)
6.	Pit training has less review and Discussion of the training session
7.	Pit training engages actual resources
8.	Combination (two or more of 1-7)

VR-based training capabilities from the VR-developers point of views:

Table 3 summarises the VR training capabilities identified by interviewing VR-developers. The VR capability list is long but here is provided a shortlist of the most relevant capabilities to this study:

Table 3: VR training capabilities from VR-developers point of view

	VR training Capabilities from VR-Developers point of view
1.	Powerful training tool when used correctly
2.	Allows safe training on high-risk activities
3.	Consultation between SME, RTO, industry and customer ensures quality training content
4.	Done properly, simulation will complement an already existing quality training program
5.	Simulation allows an additional form of training that can catch anything that may be missed by traditional methods
6.	Allows regular refresher training in a time and cost effective manner
7.	Use an agile development method to be flexible and deliver on a guaranteed shift in customer demands
8.	Development includes collaboration with training authorities ensuring that training meets standards
9.	By using blended learning, you ensure that all trainees get an opportunity to learn based on their own skill level
10.	Can replace chunks of classroom learning and compliment practical training
11.	Saves time and money while providing a wider variety of training scenarios
12.	Will create better trained crew who have been exposed to a wider variety of training systems
13.	Opportunity to get into simulation on the ground floor and get experience in best practice
14.	If developed in a flexible manner, can allow customised training scenarios to cater to different trainees needs
15.	To learn from any mistakes and make the business more productive
16.	By introducing simulation as a compliment to traditional training, you minimise risk of intimidating resistant trainers/trainees.

VR-based training utilisation from various point of views

After trainees attended the training course in VRtraining environment they were asked to answer the following four questions:

1. What were the strengths of Virtual reality as a training environment?
2. What were the weaknesses of Virtual reality as a training environment?
3. What opportunities does Virtual reality provide as a training environment/tool?
4. What would prevent the use of Virtual reality as a training environment/tool?

In order to analyse the collected data we are using Strength, Weakness, Opportunity and Threat (SWOT) analysis. However, this technique does not reflect on knowledge creation and training transfer but provides a good insight about what position is VR holding at the moment and what is going to be the future of this kind of training environment. Therefore, for those who are willing to employ VR in a more systematic and meaningful way it could be of added value to inform the decision makers, strategy planners and training coordinators to what is possible to achieve with VR and what it holds for future.
This section presents a summary of different viewpoints gathered from the three main VR stakeholders who are, VR developers, trainers using VR as a training tool and trainees who are being trained in VR. Each user has their own concerns and requirements. In the following section a combination of their viewpoints are provided in Tables 4, 5 and 6.

Table 4: SWOT from VR trainees point of view

SWOT from VR Trainees Point of View	
Strengths	**Weaknesses**
1. VR provides a high level of fidelity and realism 2. VR training is something different 3. VR training allows real-time feedback and discussion 4. VR allows training in a variety of different scenarios 5. VR training avoids real world distractions 6. VR training overcomes logistical constraints 7. VR allows safe training in high-risk activities (Controlled environment) 8. VR facilitates skill and competency creation/correction 9. VR technology is effective and easy to use 10. Combination (Two or more of 1-9)	1. VR produces Simulator Sickness 2. VR does not fit the task 3. VR cannot replace real life training 4. VR does not allow me to be physically active 5. VR training is passive learning 6. VR training not run properly 7. Combination (one or more of 1-6)
Opportunities	**Threats**
1. VR can realistically simulate events and conditions (including dangerous ones) 2. VR training allows testing and maintenance of skill levels 3. VR provides exposure to a variety of scenarios 4. VR training has better access and is more convenient 5. VR provides more opportunity for discussion and feedback 6. VR provides a good introduction and initial experience 7. VR technology facilitates training 8. Suggestions	1. Resistance to using the technology 2. Limitations of the technology 3. Cost of the technology 4. Simulator Sickness 5. Technical issues 6. Training accessibility 7. Lack of good content 8. Not knowing how to use the technology 9. Combination (Two or more of 1-8)

Table 5: SWOT from VR-Developers Point of View

SWOT from VR-Developers Point of View	
Strengths	**Weaknesses**
1. Powerful training tool when used correctly 2. Allows safe training on high-risk activities 3. Consultation between SME, RTO, industry and customer ensures quality training content 4. Done properly, simulation will complement an already existing quality training program 5. Simulation allows an additional form of training that can catch anything that may be missed by traditional methods 6. Allows regular refresher training in a time and cost effective manner 7. Use an agile development method to be flexible and deliver on a guaranteed shift in customer demands 8. Development includes collaboration with training authorities ensuring that training meets standards 9. By using blended learning, you ensure that all trainees get an opportunity to learn based on their own skill level	1. Expensive to start off 2. New methodologies and business practices need to be established 3. Still requires practical training 4. Course creation is resource intensive 5. Requires development effort for best outcomes. 6. Off-the-shelf training packages may not deliver on all training requirements 7. At this stage, technology doesn't really allow major removal of traditional training methods 8. Difficult to prove improved training outcomes due to it being anecdotal in nature. 9. Agile businesses are alien within the military/government space. 10. Small minority may be resistant to change 11. Seen as a game
Opportunities	**Threats**
1. Can replace chunks of classroom learning and compliment practical training 2. Saves time and money while providing a wider variety of training scenarios 3. Establish ownership by all parties 4. Will create better trained crew who have been exposed to a wider variety of training systems 5. Opportunity to get into simulation on the ground floor and get experience in best practice 6. If developed in a flexible manner, can allow customised training scenarios to cater to different trainees needs 7. To learn from any mistakes and make the business more productive 8. By introducing simulation as a compliment to traditional training, you minimise risk of intimidating resistant trainers/trainee	1. Seen as a luxury 2. Being seen as a magic bullet, using it instead of practical training 3. Preference to have agreement by all parties otherwise can be opened to criticism 4. Expensive to initially develop a decent asset library 5. A small minority of the population can resist change which is a challenge that needs to be managed 6. If not done correctly may not deliver training outcomes that are expected 7. Critical team members leaving and taking knowledge with them 8. Extra time and effort required during content creation stage to collaborate with all parties

Table 6: SWOT from Trainers Point of View

SWOT from Trainers Point of View	
Strengths	**Weaknesses**
1. High level of Fidelity and Realism 2. Safe and Control Training Environment 3. Create High level of Skill and Competency 4. Overcoming Logistics constraints	1. Side Effects and Simulator Sickness 2. Not realistic enough to replace underground training 3. Technology Compatibility 4. Technology Constraints
Opportunities	**Threats**
1. Realistic enough to replace theory based classes 2. Training New comers 3. Opportunity of training all different scenario	1. High Initial Investments 2. Side Effects 3. Technology Constraints 4. Limited facilities equipped with this technology

CONCLUSIONS

As a conclusion VR is capable of overcoming real world training constraints and also fulfilling the gap between real life and traditional training approaches. It is necessary to realise that the VR training tool can complement traditional and practical training and will not replace them. However this research suggests that not all scenarios can be trained for using 360-degree VR, which has prompted Coal Services to develop Desktop VR.

REFERENCES

Baysari, M T, Mcintosh, A S and Wilson, J R, 2008. Understanding the human factors contribution to railway accidents and incidents in Australia, *Accident Analysis and Prevention,* 40**,** pp 1750-1757.

Bell, P C, Taseen, A A and KIRKPATRICK, P F, 1990. Visual interactive simulation modeling in a decision support role, *Computers and Operations Research,* 17**,** 447-456.

Broach, D M and Dollar, C S, 2002. Relationship of employee attitudes and supervisor-controller ratio to en route operational error rates, *DTIC Document*.

Celik, M and Cebi, S, 2009. Analytical HFACS for investigating human errors in shipping accidents. *Accident Analysis and Prevention,* 41**,** 66-75.

Deaton, J E, Barba, C, Santarelli, T, Rosenzweig, L, Souders, V, MccolluM, C, Seip, J, Knerr, B W and Singer, M J, 2005. Virtual environment cultural training for operational readiness (VECTOR). *Virtual Reality,* 8**,** pp 156-167.

Elbardissi, A W, Wiegmann, D A, Dearani, J A, Daly, R C and Sundt III, T M, 2007. Application of the human factors analysis and classification system methodology to the cardiovascular surgery operating room, *The Annals of Thoracic Surgery,* 83**,** 1412-1419.

Jou, M and Wang, J, 2012. Investigation of effects of virtual reality environments on learning performance of technical skills, *Computers in Human Behavior*.

Mckillip, J, 1987. Need analysis: Tools for the human services and education, *Sage Newbury Park*, CA.

Misanchuk, E R, 1984. Analysis of multi-component educational and training needs, *Journal of instructional development,* 7**,** 28-33.

Patterson, J M and Shappell, S A, 2010. Operator error and system deficiencies: analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS, *Accident Analysis and Prevention,* 42**,** 1379-1385.

Raskind, M, Smedley, T M and Higgins, K, 2005. Virtual technology bringing the world into the special education classroom, *Intervention in School and Clinic,* 41**,** 114-119.

Reinach, S and Viale, A, 2006. Application of a human error framework to conduct train accident/incident investigations, *Accident Analysis and Prevention,* 38**,** 396-406.

Rushworth, A, Talbot, C, Von Glehn, F and Lomas, R, 1999. Investigate the causes of transport and tramming accidents on coal mines, Where ot be found (COMPLETE).

Shappell, S, Detwiler, C, Holcomb, K, Hackworth, C, Boquet, A and Wiegmann, D A, 2007. Human error and commercial aviation accidents: an analysis using the human factors analysis and classification system, *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 49**,** 227-242.

TRADE AND INVESTMENT RESOURCES AND ENERGY, 2013. *Human Error Classification* [Online]. Available: http://www.resources.nsw.gov.au/__data/assets/pdf_file/0005/332915/Human-Error-Pocket-Tool.pdf.

Wiegmann, D, Faaborg, T, Boquet, A, Detwiler, C, Holcomb, K and Shappell, S, 2005. Human error and general aviation accidents: A comprehensive, fine-grained analysis using HFACS, DTIC Document.

Wiegmann, D A and Shappell, S A, 2001. A human error analysis of commercial aviation accidents using the human factors analysis and classification system (hfacs), DTIC Document.