

IMPLEMENTATION AND EVALUATION OF A VR TASK-BASED TRAINING TOOL FOR CONVEYOR BELT SAFETY TRAINING

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ABSTRACT: Conveyor belts are dangerous to the working environment and the source of many injuries and fatalities that end up costing the industry a lot of money. In order to reduce the injuries that occur on an annual basis, better training techniques are examined. Virtual reality is examined as a way to enhance current training practices that consist mainly of slide show presentations and videos. Virtual reality is examined for task-based training where the user can interact with a working environment safely. The user is given tasks to complete within the virtual environment similar to tasks a worker would have to complete on a day to day basis. The purpose of the program is to be a method of rapidly training younger miners while supplementing on-the-job training practices and ultimately reduce accidents. The model was developed using CAD software and then imported into Deep Creator's Right Hemisphere where animations were added and functions were programmed to objects. The user's performance is tracked through the use of LISP programming and scores are tallied to judge user performance. The application was tested for quality of information, usability, and learning potential over other training methods.

This paper is an expansion of a paper presented at the CONVR 2007 conference at Penn State University, State College, PA, USA on October 22-23, 2007 (Lucas and Thabet, 2007).

KEYWORDS: virtual reality, safety, training, conveyor belt

1. INTRODUCTION

The mining industry, as in many other industries, places an emphasis on safety and adequate training for many pieces of machinery. Conveyor belts are one piece of machinery that is the source of many accidents and fatalities each year. Between 1995 and 2007, nearly 10% of all fatalities within the mining industry were related to conveyor belt operation (Lucas, et. al., 2008). Conveyor belts offer many benefits to the mining industry including their ability to run continuously without loss of time for loading and unloading, scheduling, and dispatching and their low transport, maintenance, power, and labour cost per ton of material moved as compared to other material moving equipment (Swinderman, et. al., 2002). With these benefits, conveyor belts are a fact of nature within the mining environment. Only with adequate training can the industry reduce accidents, reduce the amount of downtime due to accident investigation, reduce drops in production rates and lingering effects on productivity after accidents, and create a safer working environment for all employees.

1.1 Accident Statistics

Goldbeck (2003) reported that between 1996-2000 there were 459 injury cases (fatal/non-fatal) due to surface belt conveyors; 13 cases (2.8%) were fatalities and 22 cases (4.8%) were permanent disabilities; 42% of the cases reported (including 10 of the 13 fatalities) occurred while performing belt maintenance and inspection. Goldbeck (2003) also reported that the cost of a fatality in a mine was estimated to be \$1.02 million in 1986; which is equivalent to \$2.0 million in 2008 according to the US Bureau of Labor and Statistics (2008) inflation value. This value was calculated by considering medical expenses, worker's compensation, accident

investigation, loss of family income, and lost production value. Permanent disability accidents of less severity were estimated at \$237,000 and each lost-time accident was also estimated at an average of \$5,000 (Goldbeck, 2003) or a 2008 value of \$464,535 and \$9,800 respectively (USBLS, 2008). Lucas, et. al., (2008a) reviewed and analyzed 50 fatal cases involving the use of conveyor belts that were reported by the Mining Safety and Health Administration (MSHA) between 1995 and 2007. The analysis of the 50 cases involved classifying each fatality to the type of maintenance tasks being performed. Cleaning was performed during 44% of the fatalities while installation and repair was being conducted during 36% of the fatal accidents. Entanglement was also classified as the largest cause of fatalities at 56% with collapse of structure, falling of components, or loose material causing 24% of the fatalities. Based on these statistics, there is a need to explore other means to improve training for safety procedures and properly performing maintenance and inspection tasks to reduce conveyor belt related accidents.

1.2 Training Practices

Within the United States, MSHA's Code of Federal Regulations (CFR) Title 30 part 46 and 48 require 24 hours of training for new hires. MSHA requires that four hours of the training be conducted before the new hire starts work while the remaining 20 hours of training occur within the first 60 days of work. MSHA also requires documented training when a miner is assigned a new work task or transfers to a different facility. Lastly, every miner is required to participate in eight hours of refreshment training annually (CFR, 2008). Training programs are documented and approved by MSHA but guidelines on structure of a program is very limited. Training procedures and guidelines are not adequately addressed by the major professional organizations such as the American National Standards Institute (ANSI) conveyor safety standards, the Occupational Safety and Health Administration (OSHA) regulations, and the safety engineering professional associations and are left to the owner/operator to fulfil MSHA's requirements (Shultz, 2002, 2003).

Several mining facilities were visited to review how they fulfil MSHA's requirements. Typically, videos, lectures with slides, and handouts are used to fulfil the required 24 hours of safety training. Similar methods are used during the required refresher courses each year. Specific task-based training is often done through on-the-job (OTJ) training where a miner assigned to a new task is accompanied by a miner experienced in that task. The inexperienced miner in this situation is to learn from the experienced miner. Beyond the required training, the companies hold weekly or semi-weekly meetings on the site to bring up issues that happened within the industry that miners should be aware of, inform miners of any work on site considered an added hazard, and conduct a quick safety brief. Many of the companies also have incentive programs consisting of quarterly safety bonuses, awards, or group parties for successful inspections and accident free sites. It is felt by the industry that these types of programs act as an incentive for the employees to be safety conscious and help keep safety as part of the industry's culture. Even with strict regulations set forth by companies to create safety programs that go beyond the required MSHA regulations accidents and fatalities occur.

Current training programs, as discovered through site visits and literature review, are lecture-based and dependent on slides and video presentations to convey safety guidelines and procedures. These training methods are not sufficient for the wide variety of learning styles and education levels that exist within the mining industry. The demographics within mining cover a large number of employees hired during the industry boom from the 1960's and 1970's, very few hires over the following decades, and a current rising need of new, younger miners that will continue to grow in the near future (Kowalski and Vaught, 2002). A younger, more computer literate, generation may receive more benefit from a multimedia based training that they can explore and interact with while the older generations, less likely to be computer literate, often learn better from a more direct and structured approach. All adults often learn best from an active and experience based approach (Kowaliski, et. al., 2001; Kowaliski and Vaught, 2002). Current training practices do not accommodate this variety of learning styles and are passive in nature.

Knowledge learned from typical training methods, without the trainee actually reflecting upon and experiencing the information presented, may be quickly forgotten and the learning potential of the training lost (Gibbs, 1988). To enhance the learning, the material must be tested in new situations by the trainee to ensure the comprehension of the trained information. Consequences are also inadequately experienced or not experienced at all with current safety training methods. This is because the real environment would not allow the trainee to perform what-if scenarios as safely and cost-effectively as a virtual environment and because real life consequences are

often deadly. These same consequences can be simulated within a virtual environment to have a realistic effect on the trainee without the results of an injury.

On-the-job (OTJ) training has value as an active and experienced based approach by placing the miner within the real environment but still does not allow for the experiences of consequences and making mistakes without significant effects of injury or death. OTJ training can be beneficial if well planned and if the individuals doing the training are significantly trained. If OTJ training is poorly planned with inadequately trained individuals it can inhibit the proper performance of tasks and cause a rise in injuries (Wiehagen et. al., 2002). A developed VR application can ensure adequate training and offer the experience of consequences.

Virtual reality (VR) offers a potential for a safety training program to reduce the number of injuries and fatalities through the representation of real-life events in an artificial environment. VR offers a cognitive learning method for trainees to think through actions needed to complete tasks, act them out in a virtual environment, and come in contact with direct consequences to their actions while receiving immediate feedback. With the user having control over the environment and playing out tasks and activities, it is more likely they will be able to perform those tasks safely in real life situations. Testing methods can also track user performance and determine a user's skill level. It is this cognitive learning experience that places interest in the use of VR for task-based training.

Current training methods do not offer an effective way of training a nearing surge of young hires that are needed and will be recruited in the near future. A VR application for task-based training is proposed as a possible solution to effectively train new miners of required safety procedures and hazard recognition information for conveyor belt use and to improve safety within the actual working environment. A four step VR-based safety training program for conveyor belts is developed (Fig. 1). Through data collection at site visits and literature review, specific training areas were identified. The training was implemented in a prototype application that consists of two modules, an instructional-based module (Lucas, et. al, 2008a) and a task-based module. The instructional-based module introduces the collected data and the defined training areas to the user and the task-based module tests the knowledge of the user to help determine the user's skill level. Upon completion of the prototype implementation the application was evaluated to ensure it meets industry needs, offers a usable and useful interface, and is perceived as an effective way of learning material. The goal is to create an effective method for safety training professionals to efficiently train new younger miners and ultimately reduce injuries within the industry.

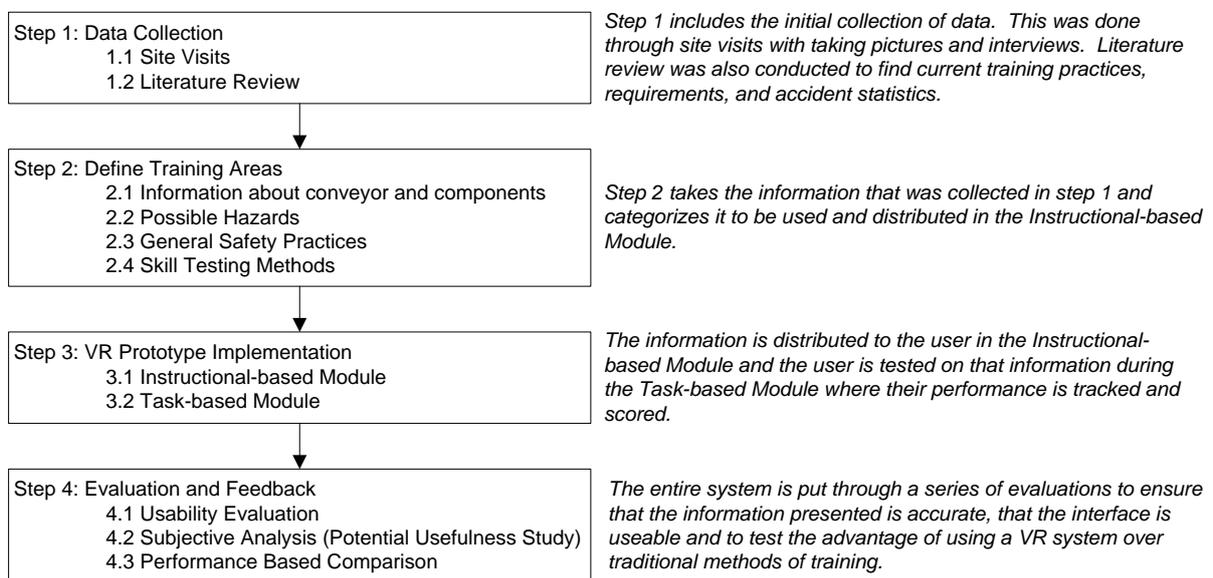


Fig. 1: Four steps to safety training program structure

In addition to the testing and evaluation of the prototype application using a personal computer, the application has been imported to an immersive CAVE environment. The effectiveness of learning as well as the advantages and disadvantages of the immersive CAVE application versus the non-immersive personal computer applications is being studied (Lucas, et. al., 2008b).

This paper is concerned with the development and evaluation of the second phase of research for the personal computer prototype. Within this phase a prototype implementation for the task-based module (step 3.2) is developed. Current training methods and benefits of VR and cognitive learning and how they can benefit the industry within a safety training program are explored. Current VR task-based training research is presented. The paper discusses in detail the skill testing methods (step 2.4), their implementation in the task-based session, and how the user's actions are tracked and feedback is given to the user. The evaluation scheme (step 4) and select findings are also discussed.

2. COGNITIVE LEARNING AND VIRTUAL REALITY IN TRAINING

Training has evolved from traditional classroom training to computer-based interactive training in many fields. Classroom training is utilized because of the knowledge that a quality training professional can instill in trainees during classroom sessions, however computer-based training is becoming more popular in all sectors as it is believed to enhance the cognitive learning of the user. Cognitive learning is a process of acquiring knowledge and understanding through thought, experience, and the senses. The information that is acquired through cognitive learning undergoes a process known as cognitive information processing (CIP). CIP is based on the thought process behind the behaviour and is used when the trainee plays an active role in seeking ways to understand and process the information received and relating it to what is already known and stored within memory. CIP seeks to explain how learning occurs in a "multistage" theory of memory. In this model of learning, the human mind collects information and moves it around to be associated with other existing related pieces of information and stored in larger files (Driscoll, 1994).

A similar model of cognitive learning is the integration of working memory and long-term memory. Working memory is the "center of cognition and scaffolds all the active thinking activities that occur" (Clark & Mayer, 2003). Working memory deals with the consciousness of our everyday lives (Baddeley & Hitch, 1974). Where as long-term memory is the final stop in the cognitive information-processing path where the information is permanently stored (Shiffrin & Atkinson, 1969). Integration of new knowledge from working memory into long-term memory is called encoding. Later this knowledge from long term memory retrieved into working memory to apply it within a real-life context. Thus the learning progress reaches completion when acquired knowledge is successfully retrieved and applied in multiple contexts (Clark & Mayer, 2003). Meaningful learning ensures that well learned content held in long-term memory is easily brought into working memory. Retrieving and applying the data stored in long-term memory is crucial to solving high level problems involving complex interactivities (Ericsson & Kintsch, 1995).

These theories of cognitive learning can be applied to virtual reality training. Within a VR training environment, the user goes through a series of training (instructional-based session) and rehearsals (task-based training). Unlike with traditional slide show methods and videos, it is an active learning experience where the user is in control. The situations that the user is put into virtually require them to think out proper actions. If improper actions are taken the consequences are immediately shown. These actions and reactions as the user goes through the system are placed in working memory until they are encoded into a larger file of similar information in the long-term memory. When the user comes across a real-life situation the appropriate knowledge is retrieved from long-term memory and applied to the situation (fig. 2) where the user would already know of the consequences of mishandling a situation.

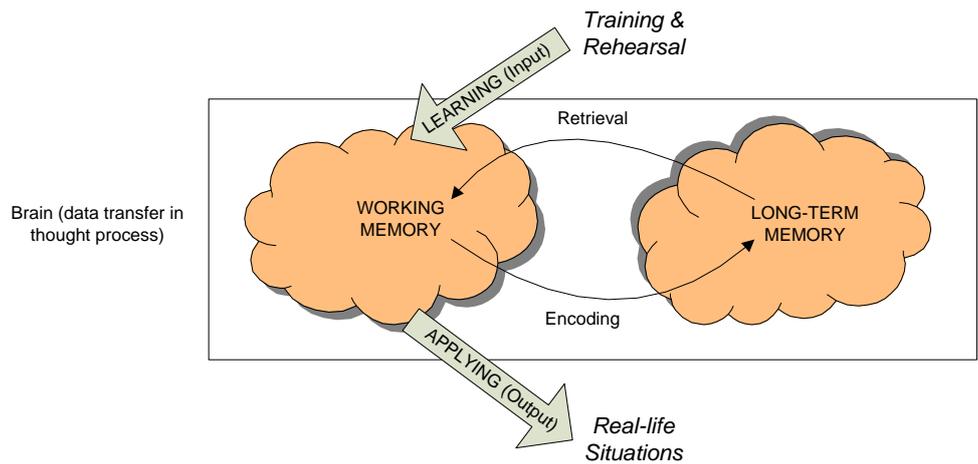


Fig. 2: A VR application allows for rehearsal of activities, experienced to be stored, and retrieval in real life.

With the use of cognitive learning theory research has shown that computer-based training applications can enhance the training process and give the trainees a better understanding of the material when they are interactive and active in nature. Some work that has been done by using VR and computer-based representations for crisis simulations are: for fire-fighters (Querrec, et. al., 2001), mine safety training (Filigenzi et.al., 2000), security in a refinery (Haller, et. al., 1999), buildings' fire detection systems (Bukowsky, et. al., 1997) and shipboard fire fighting training (Tate, et. al., 1997). Some other examples of VR simulation that replicate an action/reaction scenario and task-based training methods within the mining industry have been conducted by the School of Mining Engineering at the University of New South Wales, Australia with simulated situations of safety in underground mining dependent upon an individuals actions (Stothard, et. al., 2004). Similarly, work at the Spokane Research Center (NIOSH) used VR to test the knowledge gained through training by giving trainees tasks within a VR environment to complete safely (Orr, et. al., 2003).

Other uses of VR within the mining industry include the use of virtual environments to improve safety and design through information visualization and accident simulation (Dellabio et. al., 2007) and accident recreation (Shafrik, et. al., 2003). Virtual environments were also researched for use with underground mine safety training, procedural training, and identifying hazards (Ruff, 2001). Different studies were conducted by Dezelic et al. (2005) and Kizil and Joy (2001) using VR for equipment operation. Stothard, Galbin, and Fowler (2004) used virtual reality applications for health and safety activity simulation.

A VR simulation should replicate the work environment into which a trainee will be placed and then test the trainee with a problem based learning exercise (McAlpine & Stothard 2003). A simulation should also include a method of testing trainee's ability to identify and remedy risk with a method to quantify. In order to enhance the cognitive learning process, the simulation should also demonstrate to the trainee the consequences of poor decision-making and risk taking behaviour (Stothard, et. al., 2004). VR applications and the use of virtual environments have been used with great success because of their ability to safely simulate real life events in a digital environment that might otherwise be too dangerous or expensive to create (Haller et al, 1999).

During literature review no research was found that uses VR to target the need for training a high rate of younger employees or train employees on safe operation of conveyor belts, a piece of machinery that is one of the leading causes of injuries and fatalities within surface mining operations. With the models of cognitive learning coupled with the ability of VR to simulate a realistic working environment, a task-based session is researched for safety training with the use of conveyor belts in mining. This prototype replicates a working environment, trains the user of the information that they will be responsible for, and lastly tests the knowledge by assigning a task to be completed. This process is described later in the paper.

3. TASK-BASED PROTOTYPE

3.1 Task-based Prototype Development Framework

The task-based prototype uses the model of cognitive theory for the training of new miners and testing their knowledge and skill level of the information distributed to them in the first phase, the instructional-based module. Each exercise is designed by using a five part framework that evolves around instructional design theory and the ADDIE (Analyse, Design, Develop, Implement, and Evaluate) model (Leshin, et. al., 1992). The prototype development also takes advantage of a more advanced instructional design model the Eternal, Synergistic Design and Development Model that revolves around the user's needs and their critique and feedback (Crawford, 2004), by taking advantage of mining industry personnel at various stages of the prototype design and evaluation to ensure it fits industry training needs.

The five part framework for the prototype development and testing (Lucas and Thabet, 2007) consists of (1) determining skills to test, (2) defining training scenarios, (3) determining consequences and reward, (4) animation and programming, and (5) testing for quality assurance. In each exercise it is essential to determine what the user will be tested on by forming a reasonable selection of activities to place within one exercise for the user to complete while in the virtual environment. The environment and scenario then needs clear definition so the user will know what it is they are looking to complete. With an idea of what the user will need to complete within the environment, feedback given to the user and questions asked to the user have to be defined with a tally system to keep track of the user's actions. Once the actions and reactions are defined, they have to be animated and programmed within the system, and lastly the system is put into implementation for testing and quality control.

Flowcharts were used to map the five major tasks and their subtasks that the user needs to complete within the session. Detailed flowcharts were created for complicated tasks that required further definition. With these detailed flowcharts (fig. 3) step by step animations were added to correspond with user input.

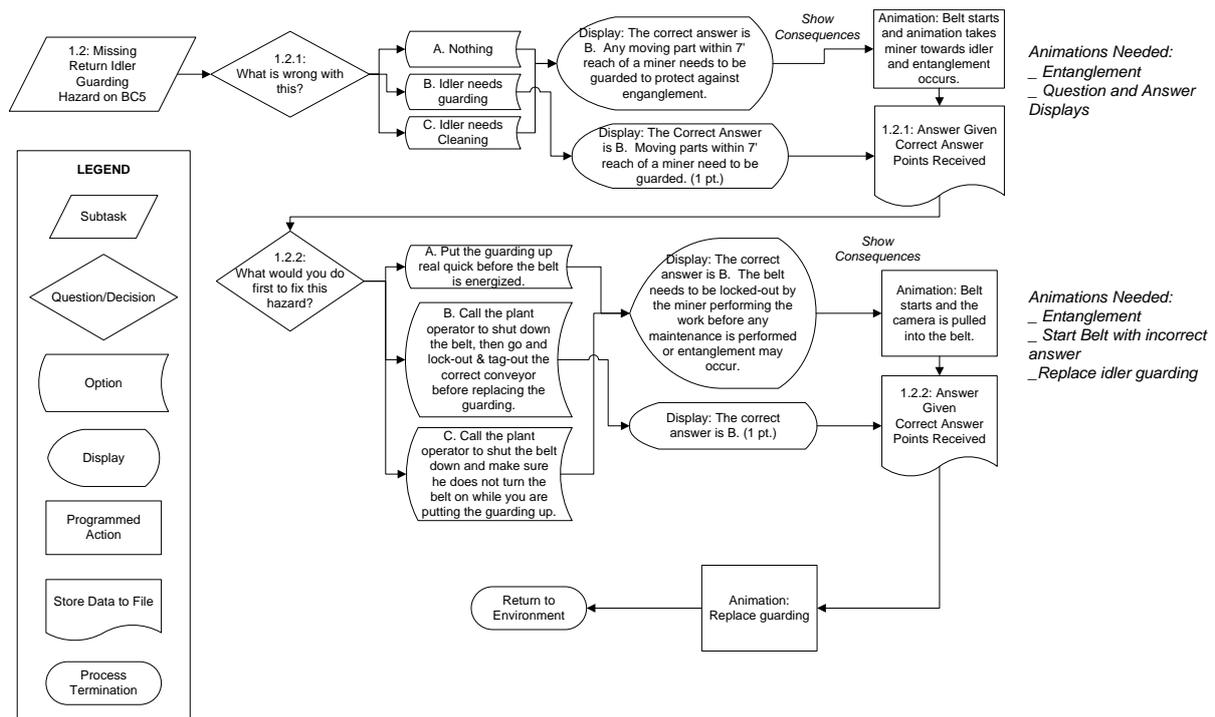


Fig. 3: Partial scenario flowchart

Figure 3 shows an example of a sub-task where the user is to identify the hazard of a missing idler guard. With each sub-task certain animations were developed. In this example, there were questions that the user is asked during the session. The questions that are displayed with each of the possible answers were put into the flowchart. This aided in the programming to know what information was needed to display with a

corresponding user input. Animations and consequences were also added to the flowchart where they would need to be activated within the prototype and shown to the user.

3.2 Scenario Implementation

Once the background research to select development topics and define objectives was completed, the virtual environment was programmed to create the training application. This was completed by taking the 3D model that was created in Autodesk's 3DStudio Max for the first module of the application, exporting the model as a .3ds file, and importing it into Right Hemisphere's Deep Creator. Deep Creator offers basic modelling capabilities and basic animation features. Deep Creator also offers a LISP editor where scripts are easily added to each object with the use of trigger controls for controlling animations, system variables with "if/then" statements, and loops, for more advanced animations and interactions.

With the previously completed model, the initial task-based scenario was developed over the course of a few months with approximately 100 man hours that included the learning curve for the application and trial testing before presenting it to the industry. Within this time period the environment was programmed with basic features to make the conveyor belt appear as it is working. After the basic animations were added, the flowcharts were used as a basis for programming the scenario, adding the questions, answers, and consequences, and tracking the user's progress through the prototype.

The basic animations were added to the system with a few different methods. First, materials were added to the different parts of the model. This gives the environment a more realistic appearance. From this, the components that need to be moving when the conveyor system is turned on were programmed. In order to achieve the appearance that the belt is moving the idlers need to rotate and the belt needs to appear that it is moving across the idlers. This was done by adding the basic rotate animation to the idlers, applying the proper axis rotation and designating a rotation speed. Then, the material mapping previously applied to the rubber belt needs to move across the rotating idlers. This was accomplished by assigning the "material move" animation. This animation keeps the object stationary, but makes it appear to be moving by taking the applied mapping and sliding it over the surface of the object. Other noise and bump alterations were added to make the belt appear to vibrate.

Once the animations were applied the ability to turn them off and on was programmed. This can be done through the use of trigger animations and one trigger object but it would require an extremely high number of animation call functions all assigned to one object. The easier method of accomplishing the same task was to write a script using the LISP editor. As the animations were set to "trigger" when they were applied to each idler and the belt in the object tree, they were given the same name with a number suffix (e.g. TI1, TI2, etc. for troughed idlers) (fig. 4A) allowing for a loop to be written into the code (fig. 4B) and attached to a trigger object, in this case the start and stop buttons that turn the objects' animations on and off (fig. 4C). Once the trigger object is selected when the application is run, the loop calls the name of the component and then runs through all subsequent components that are associated with each piece of the belt.

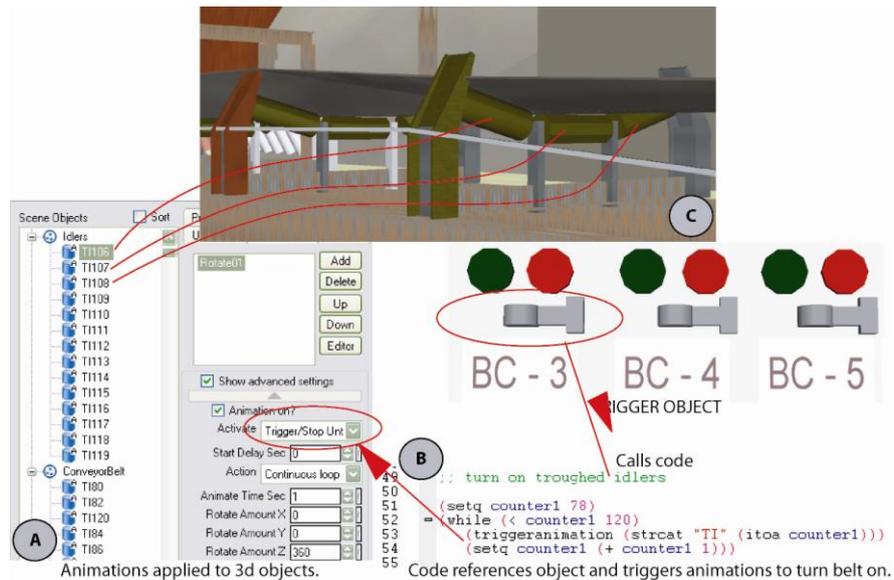


Fig. 4: Turning on and off the Conveyor Belt

Another layer of information that the start and stop buttons rely on is making sure the breaker is turned on and not in the off position, a factor from the real life environment that needs replication within the virtual environment. This again is done with the use of the LISP editor and the introduction of an “if/then” statement that was added in front of the series of loops that turn the belt and idlers on or off. The “if/then” relies on a system variable called “lever” that returns a 1 or a 0 depending on if the breaker is on or off (fig. 5). As long as the breaker is in the on position it will run the loop and turn the belt on. This process was repeated for each of the three conveyor belt sections.

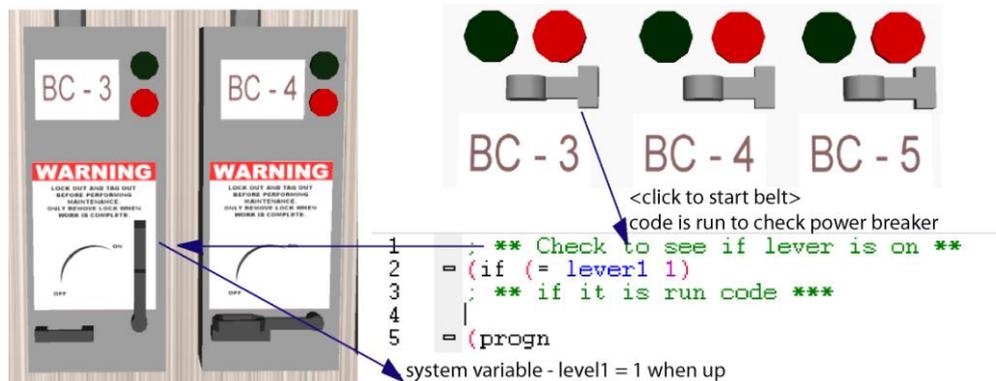


Fig. 5: System checks to make sure breaker is on.

Once the basic features of the environment were programmed, the programming for the specific scenario and tasks was completed. This was done by taking the previously developed flowcharts and following the laid out processes. The first task developed was the “Identify Hazards” task where the user has to navigate through the environment and find three different hazards. In order to program this task, a series of questions and possible answers were added to the environment that the user will be asked. The questions and answers were connected to the hazard in the environment and the application keeps track of which hazard the user identifies first and which answers the user selects. In order to program this, the questions that are associated with each hazard were added to the environment as text blips that appear as message boxes. They were then connected to the trigger object at each hazard. The possible answers were also added to show when the questions appear. The explanations to each answer was then placed as another message box, each of which would appear when the right or wrong answer that it is connected to is selected. Consequences for each wrong answer were animated and are triggered by selecting that wrong answer (fig 6.). The code written in the LISP editor controls the message box that appears when each answer is selected by the user. This allows the programmer to easily keep

track of and program what appears with each user input. Another reason why the LISP editor was used for this process is that the prototype keeps a tally of how many hazards have been identified by the user so once all hazards are identified the application can instruct the user to move on to the next task. The prototype knows which task message to show based on “if/then” statements and a system variable (fig. 7). The prototype also keeps tally of which answers the user selects and prints them out to an output file at the end of the session and tallies the points received by the user to help the trainer keep track of the user’s performance.

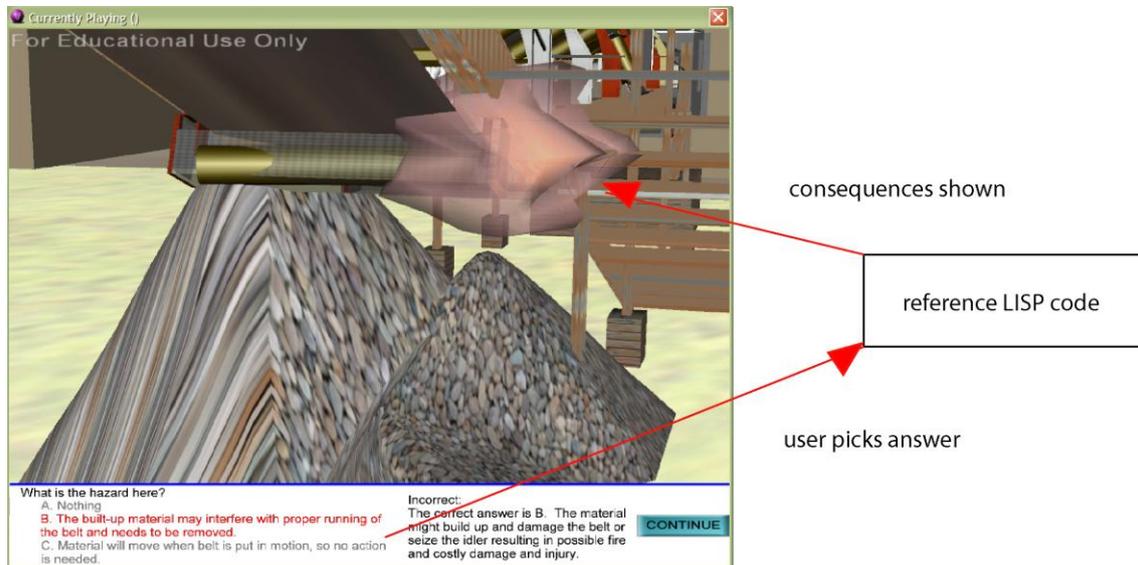


Fig. 6: Identifying hazards – question/answer example

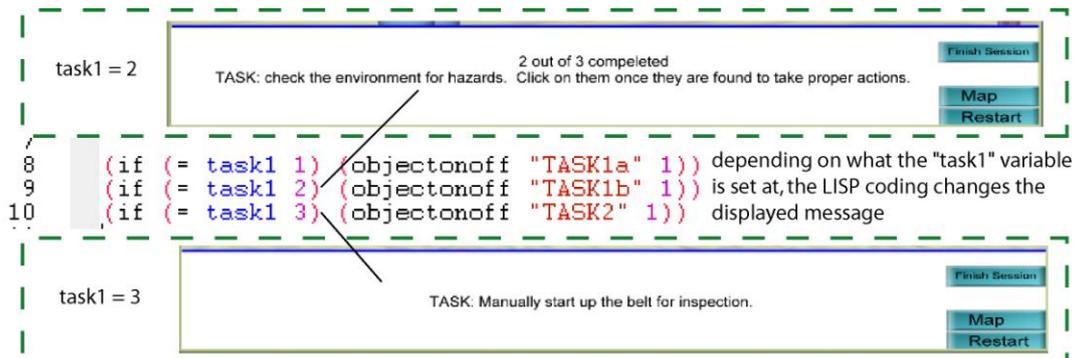


Fig. 7: Task message example

Another programming feature used for identifying the user location in respect to the hazard to trigger animations, such as the broken rail, is a proximity sensor. Proximity sensors were used and set at the edge of the catwalk where the broken rail is located. If the user navigates too close to the area of the broken rail, animations are triggered that make it appear that the user has fallen from the catwalk. The proximity sensor consists of placing an object, which does not render while the prototype is run, along the catwalk. Another object, that does not render, was tied to the navigation window and follows the user around the environment. Once the two objects collide the animation is triggered.

Once the user identifies the hazards, the next step in the flowchart indicates that Task 2 is to turn on the conveyor belt system. In order to properly do this, the user must make sure that the electricity breakers are in the “on” position, navigate to the control room and sound the alarm, and then start each section of belt. This involves programming that was built off of the initial environment programming that makes the belt look as if it is moving. First, each breaker has a system variable tied to the control switches. As long as this variable is set at “1” the control switch turns the belt on. The control switch also looks for a variable to make sure that the alarm was sound within 30 seconds of the switch being selected through the use of stored times (fig. 8). If the alarm was sound longer then 30 seconds before the user tries to turn on the belt, or was not sound at all, there is a

warning message telling the user of the proper procedures. If the user does not follow the proper procedures during their first attempt to turn the belt on they will not receive the points available for completing the task correctly. This process of manually sounding the alarm mimics the basic manual method of turning on a belt in real life. Commonly, computerized systems automatically sound the alarm before starting up the section of belt, but it was felt that programming, and training the user on, the most primitive method that an employee may have to use was important for the success of the application. Once the belts are turned on, the user is charged with the next task of inspecting the belt to make sure it is running properly.

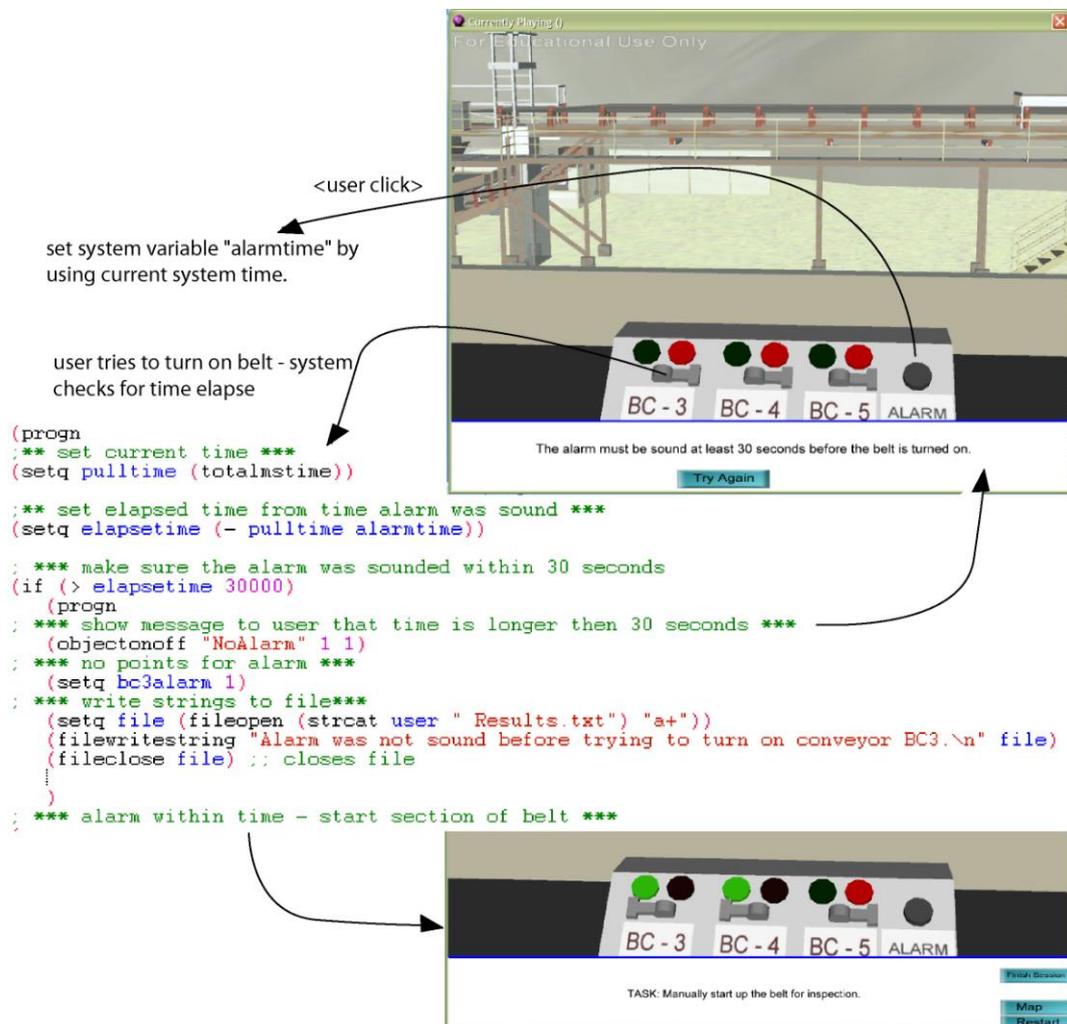


Fig. 8: Sounding the alarm.

The third task that the user has to complete is to inspect the conveyor belt system for any malfunctioning components. There is a smoking idler located along the lower conveyor belt. Once the idler is recognized, the user is able to radio to the control room and have it shut down. After making sure the belt shuts down, the user needs to turn off the breaker and lock and tag it out (task 4), remove the idler guard, fix the idler, replace the guard, unlock and power on the breaker, and start up the belt (task 5). Each one of these steps happens in a specific order to properly complete the task. At certain stages of the process if the user completes something out of order certain consequences can happen. If the user does not shut down the belt, or lock it out, and removes the guard, it is possible that the employee in real life would be injured. Another possible consequence is if the belt is turned on without the guarding being replaced, a similar situation can occur. One last possibility is if the breaker is pulled before the belt is shut down it is likely to explode. Each of these consequences was programmed in the prototype and is triggered by the use of system variables and “if/then” statements in the LISP editor. If one of the trigger objects is selected, such as the guarding clicked to be removed, the application runs lines of code that check to see if the variables are at the proper value. For the instance of removing guarding, the

system checks to ensure the belt is shut down and the breaker is turned off and locked out. If everything clears, the user is notified of “guarding successfully removed” and the guarding is moved away from the idler. If the belt is still on, an animation is triggered and the user is pulled into the conveyor showing the user became entangled into the moving conveyor, which is likely a fatal injury. A message is shown and the event is recorded. The other consequences are programmed in a similar manner.

Once the user completes all tasks that are programmed into the system the application produces an output file as a .txt file (fig. 9). This file is created through LISP coding associated with each task the user had to complete. Depending upon what answer is selected depends upon what is written to the file. Also, the coding records each step that the user takes to the file. If a step is missed or the user does not complete the steps in the proper order, it will appear in the text file.

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                                Jason Lucas Results
Task-based Session 1: Beginning of shift start-up.

Task: Start the shift by inspecting the belt to ensure all safe guards are in place
and all hazards removed. After energizing the belt, make sure it is running
properly before going on break.

Environment Conditions: Start of shift, the belt is de-energized, unlocked, and
there are no other employees in the work area.

User's Name: Jason Lucas

Order of actions:

ACCUMULATION HAZARD:
  Q1. What is the hazard here?
  User answered: A. Material will move when the belt is put in motion, so
    no action needs to be done. - INCORRECT
  Q2. How would you fix this hazard?
  User answered: C. As long as guarding is in place, shovel material out of the
way or use a
    hose to wash it out. Check for the cause of the accumulation and fix it. -
CORRECT, +1pt.
.....

Alarm was not sound before trying to turn on conveyor BC3.
Belt BC3 successfully turned on.
Belt BC4 successfully turned on.
Belt BC5 successfully turned on.
Belt BC3 turned off by radio call.
Power for breaker BC3 is turned off.
Break BC3 is locked-out.

.....

Session finished.
Total is 11 out of 13.
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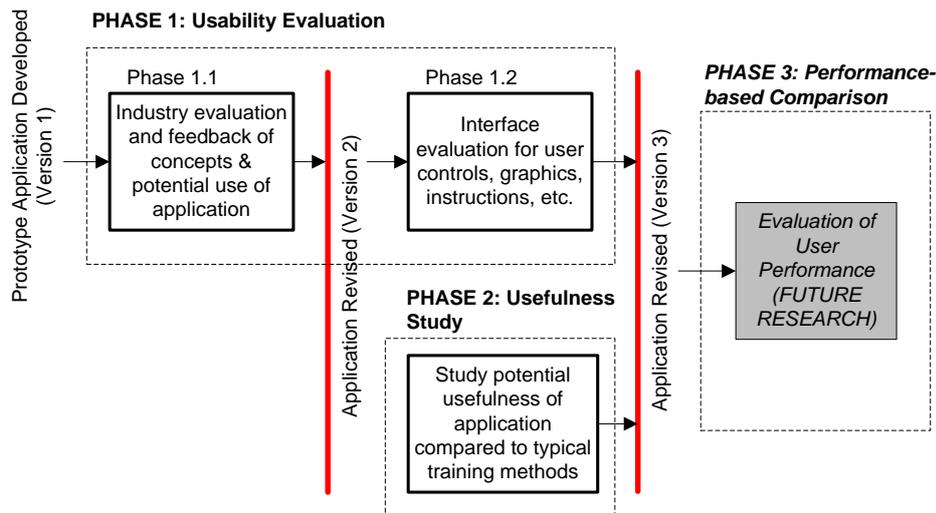
Fig. 9: Sample from output file created at end of session.

After the programming was completed it was important that the application was tested to make sure that all options the user can take work properly. The process of debugging the application is a repetitive running of the program and completing tasks in different steps to make sure that the proper animations and actions will work in any possible combination when it is used. Deep Creator has a built in “play” function for the environment which aids in viewing the work that has been completed as the user will interact with the environment. Once a bug is found, the programming code is examined to make sure that the “if/then” statements and system variables are working properly. After all the bugs were removed, the session was exported from Deep Create as a self-executable file (.exe) and placed through the feedback and evaluation process using industry professionals and various other users to check accuracy and completeness of information and usability.

The challenges that exist with the creation of the prototype include the learning curve of the program. Overall, the programs modelling features work similar to that of any other modelling environment. The programming was easy to become familiar with and the help files aided in the understanding of these features as well as the built in animation/alteration functions. Some benefits of using Deep Creator to program the environment was that the built-in features were easy to get used to, and most of what needs to be done can be completed within assigning properties to each object that control animations and trigger events. The LISP editor features of the program aid in a quicker development once controls become complex and only basic knowledge of the programming language was required to program complex processes. Methods of trial and error were used in order to fully understand the limits of features of the program and overcome barriers presented by the basic program functions.

4. FEEDBACK AND EVALUATION SCHEME

After initial implementation of the prototype application a series of studies were conducted to ensure that the application would fit the needs of the industry, was usable, and had potential usefulness. The evaluation scheme (fig. 10) consists of three phases: (1) a usability evaluation, (2) a usefulness study, and (3) a performance-based comparison (future research). The evaluation process is an iterative process where a study is performed to collect information that is then used to improve the prototype application. Phases 1 and 2 consisted of qualitative subjective studies dealing with personal perceptions. These subjective studies documented participant perceptions of usability and usefulness of the application through the use of questionnaires. Phase 3 (future research) will involve an objective comparison of user performance and will allow a comparison based on participants' performance in a scored evaluation.



Phase	Purpose	Participants	Study Type
1.1	Industry review of information, concepts, and potential of application	Industry Experts	Subjective
1.2	Evaluation of user controls, navigation and interaction with environment	Expert & Novice Users	Subjective
2	Perceived advantages and shortcomings of proposed application vs. typical training methods to determine prototype usefulness	Expert & Novice Users	Subjective
3	Evaluation performance of new trainees after they complete training with application or typical methods. Results compared.	Novice Users (Inexperienced Miners)	Objective

Figure 10: Evaluation scheme for prototype application

4.1 Phase 1 – Usability Evaluation

Phase 1, the usability evaluation was broken into two sub-phases, an industry review of presented information and comments and an interface evaluation. The industry review sessions were used as an indicator for industry interest in the prototype application. The interface evaluations were conducted to identify bugs within the application, identify weaknesses in usability, navigation controls, instructions, graphic representation of information, and ability to complete tasks.

Phase 1.1 was conducted through unstructured feedback sessions. In each of the sessions the meeting attendees were presented with a concept overview of the application prototype and then a demonstration of the prototype. During the demonstration the attendees were encouraged to make comments about what they were presented and interrupt at will to discuss any issues, questions, or comments they may have. Overall four meetings with three companies were conducted with a total of 11 professionals in attendance. All consulted companies are based or have operations within Virginia, USA, are aggregate processing plants, and have extensive use of surface conveyors within their operations. The industry professionals consisted of three individuals involved with safety

programs at their facilities, two training professionals, and the remainder were superintendents, foreman, maintenance personnel, and engineers. After each meeting the feedback received was used to revise the information creating an iterative review process (fig. 11). When all meetings were conducted a second version of the prototype application was created for the next phase of evaluations.

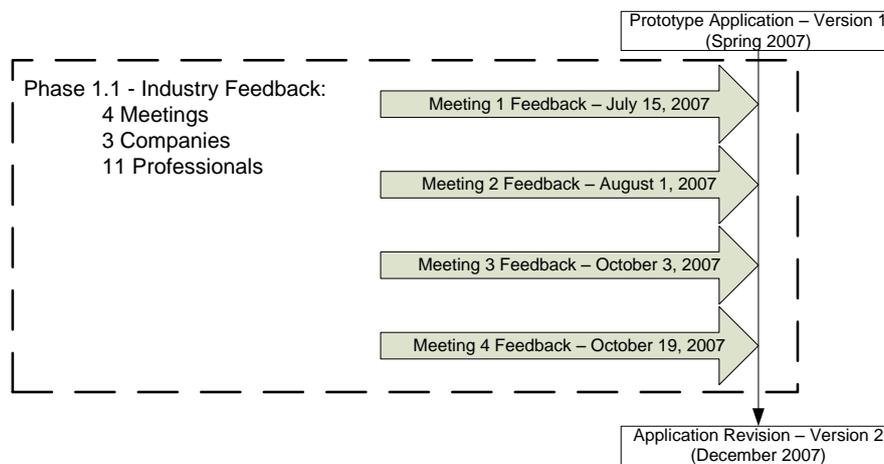


Figure 11: Phase 1.1 of evaluation process

From the review sessions 28 unique comments were documented, of these 28 comments 13 were dealing with revisions to existing information while the remaining 15 were suggestions for improvement or suggestions for future scenarios that can be developed. All the received comments were reviewed and the application revised.

The secondary purpose of the industry sessions besides review of information was to judge the level of industry interest in using a personal computer based virtual reality program for training. The following reasons were given during the meetings in support of developing such an application:

- The application gives a sense of interaction, especially to the younger generation used to working with the computer and playing video games.
- It offers an interaction and practicing of procedures in a close to life environment.
- Different people learn different ways and this would offer a better method of teaching to some who do not do so well with other methods of classroom type training.

A complete list of revision comments compiled during industry feedback is documented in Appendix A.

Phase 1.2 consisted of both novice and expert knowledge level participants. Each participant was given a description of application and presented with the purpose of the research. They were then asked to complete the training application by reviewing both modules of the prototype. Once they reviewed the modules and participated in the task-based training, each participant was asked to fill out a questionnaire and rate their agreement, on a one to five scale, to statements on the questionnaire from strongly disagree (1) to strongly agree (5). The statements that were used are classified under five categories: 1.) clarity of instructions, 2.) ease of navigation, 3.) clarity of objectives, 4.) understand ability of information, and 5.) ease of completing tasks.

12 individuals participated in the interface usability study. 10 were students and 2 were mining professionals. 10 were male and 2 were female (both females were students). The average age of the participants was 28 years of age with a range from 20 – 40. One of the mining professionals was in charge of safety training at the time of participation; the other was in charge of a training program earlier in his career. 11 of the participants (9 students & 2 professionals) have had experience with first person video games before participating in the training. 9 of the 11 had experience using mouse and keyboard controls similar to that of the task-based module of the prototype application. All expressed their rate of play of these types of games as “not often” or “less than 5 hours per week”.

The average agreement for the interface evaluation survey statements are listed in figure 12 (survey statements are listed in Appendix B).

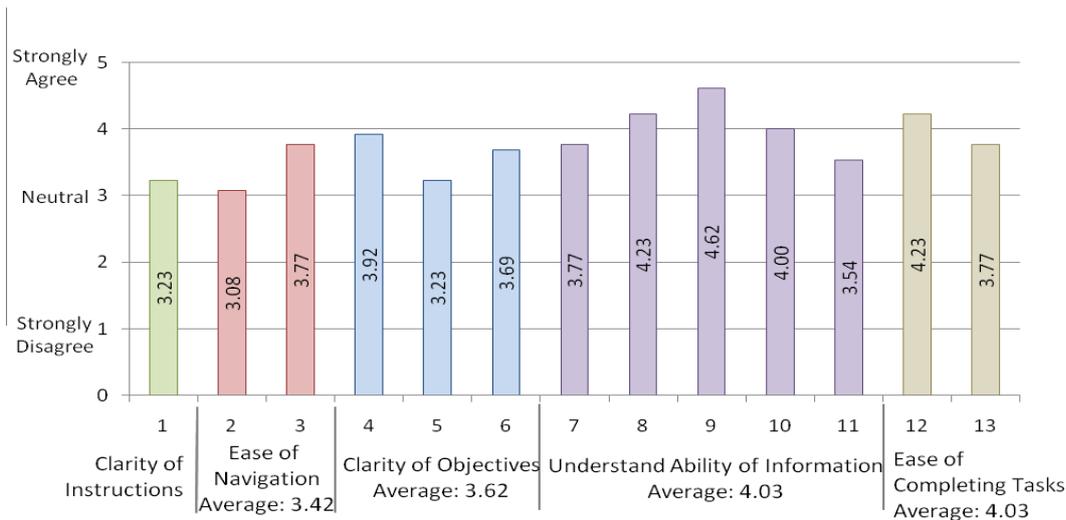


Figure 12: Average agreement for Phase 1.2 Interface Evaluation survey statements

Upon examination of the findings some key issues were identified. The instructions were given at the beginning of the session, however since there are several stages to the session they were difficult to remember. Some individuals had difficulty understanding some of the instructions. These issues were resolved by editing the way in which the instructions were written as well as giving the user reminders of the tasks they are to complete as they continue through the session. The same issues existed with the clarity of the objectives. The individuals who disagreed with the statements about clarity of objectives gave suggestions on how some of their confusion could be resolved. Lastly, navigation proved to be the largest issue to most of the participants. Some participants were able to overcome any challenges and familiarized themselves quickly with the navigational controls while other participants found the navigational controls a major issue and were easily disorientated within the environment. If the application were implemented into the industry, additional studies would need to be conducted to see which navigational control methods are favoured by the most individuals. Some controls to include in this study are game console controllers, joysticks, touch screens, or the use of keyboard and mouse navigation with different settings and methods for use. No matter which method is found the easiest for the most individuals cues can be added to aid in navigations. One example of a navigational cue is if the user navigates to the doorway of the breaker room within the environment the application would automatically re-orientate them to the breakers on the wall where they would interact with the environment while completing their task.

A full list of statements and their average rates of agreement and distribution is listed in Appendix B.

4.2 Phase 2 – Usefulness Study

This study was conducted with the use of a subjective survey designed to capture participants' perceptions of the advantages and shortcomings to learning with a VR application as opposed to traditional training methods. Both novice and expert knowledge level participants participated in this study. Novice knowledge level participants were given a presentation of typical training material as used within the industry and a demonstration of the prototype application, participants were allowed to navigate through the environment and experience the training method. The typical industry training material included several PowerPoint slideshows received from industry contacts, training videos available through MSHA and other organizations for the purpose of training at mining facilities, and printed documents used within the industry. Once the presentation of the training material and demonstration of the application were completed each novice participant was asked to complete a survey to document their preferences of learning methods and advantages and shortcomings of each training method. The expert knowledge level participants were given the demonstration of the prototype application and allowed to experience the training and then asked to complete the survey comparing the prototype application to the training methods they were familiar with that are used at their own facility. Figure 13 is a graphical representation of the structure of this phase.

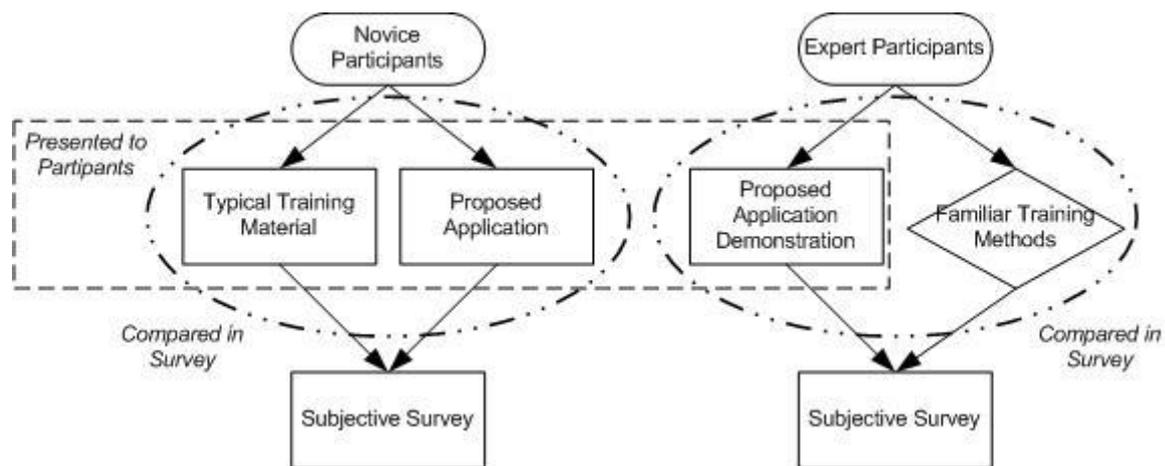


Figure 13: Phase 2 – Usefulness Study – study structure

A total of 8 individuals were asked to participate. 2 participants were mining professionals the rest were novice experience level participants.

Some of the common comments documented from the survey as being advantages of using a VR application for safety training were that it allows for the rehearsal of tasks, allows for the experience of consequences without the danger of the real life environment, and offers an interactive training. The shortcomings that were of the most concern were that the VR application requires some computer knowledge and ability to navigate through the environment. This would be difficult for the older generation or individuals who are not computer literate.

5 of the 8 participants agree they would prefer learning from a VR application. The reasons stated were:

- That the VR gives them an interactive experience where they could rehearse processes safely.
- That the users were able to view processes step by step in the instructional-based session and then try them out in the task-based module.
- That the interaction gives them control over their training.

The 3 participants that preferred typical training methods over the proposed VR application cited that the typical training methods allow a personal interaction with an individual of experience who can answer questions and that the typical training methods allow for learning by individuals who do not need to be computer literate or for individuals who learn better in a classroom setting. These participants did agree that there are benefits from using a VR application for training and that it was an effective way to learn for a younger, computer literate, audience.

4.3 Phase 3 – Performance-based Comparison

This phase of the evaluation will be completed as part of future research as it is beyond the scope of the NIOSH funded research. This phase would involve a developed functional VR application and only be conducted after a navigational control system is found that is easiest for most individuals to use. This study would include an objective comparison of miner performance. Two test groups of novice knowledge level will be needed to complete the performance-based comparison study (Figure 14).

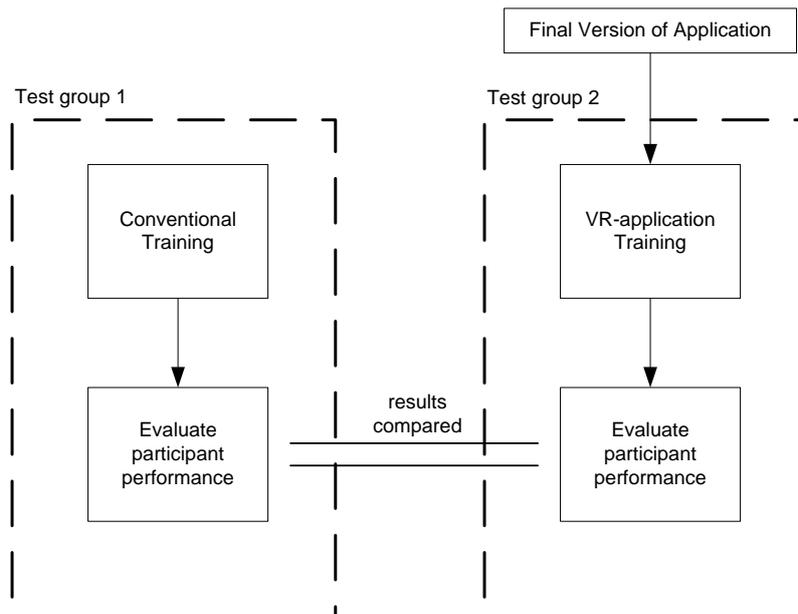


Figure 14: Phase 3 - Performance-based Comparison – Study Structure

The first test group would participate in typical training that is customary through the industry. A second test group would participate in the VR application training. Each individual who participated in either test group would then be subject to a performance evaluation. This performance evaluation can be paper-based and conducted on the knowledge the user should have gained through the training or it can be based in the field where the users are given a task to perform and their performance is then evaluated through a structured review process. The results of the performance of the two groups will then be compared and evaluated to see if there is one training method that is more effective than the other group.

To expand this evaluation phase a long term industry evaluation of the training and effectiveness can be conducted by reviewing, at regular intervals, the performance of individuals who participate in different methods of training. Accident rates and skill levels can then be assessed for long-term benefits in training methods.

5. IMMERSIVE VERSUS NON-IMMERSIVE EFFECTIVENESS COMPARISON

After the implementation of the VR application prototype was developed a second research group recreated the application within a 4 screen CAVE environment at Virginia Tech. With an identical VR application running on two separate platforms, a study is being conducted to test the effectiveness of learning and knowledge gain from training in an immersive, CAVE environment, or a non-immersive, personal computer application (Lucas, et.al., 2008b).

There is often perceived benefits of using an immersive environment over that of a non-immersive personal computer because the environment becomes life-size allowing for better perception and further engaging the user, however the size of the CAVE environment and precision set up required rises issues with accessibility to such training applications. If a CAVE environment was used for training the trainee would have to travel to a specific facility. With a personal computer application the trainee can be trained in the local office or in the back of a truck with a laptop. The flexibility of the training environment is greater with a personal computer. The purpose of this study is to try to determine which method is more effective and if the CAVE environment is more effective for learning is it worth the cost of implementation and lack of flexibility. The study uses two groups of novice knowledge level participants who have had no previous experience to conveyor belts or mining. After each participant completes the immersive or non-immersive training module they are given a test the knowledge gain from the two groups are compared. This study is ongoing and will be published with the results of the NIOSH funded research.

6. CONCLUSION AND FUTURE RESEARCH

The aim of the developed prototype application and subsequent research studies is to examine the potential usefulness and effectiveness of a VR application for safety training for surface conveyors. The goal is to offer safety training professionals a tool that can help them adequately and effectively train an oncoming influx of younger miners that are needed in the industry over the next few years. After completing the subjective studies the results and received data were analyzed. Though there were some usability issues identified through the usability evaluation, the issues with clarity of instructions and clarity of objectives are easily overcome through revisions of explanation. The issues with navigational controls can be overcome with further evaluation studies. Other than the identified usability issues there was initial industry buy-in to the concepts and perceptions of that a VR application offers a useful tool for training younger miners. Within the usefulness study similar perceptions were documented that indicate a potential for a VR safety training application with conveyor belts. Though a true effectiveness cannot be determined until a performance based evaluation as previously described is performed, the responses from the industry and other consulted individuals offer a sense that further development of a personal computer based training application can have a positive effect on training. Industry members feel that allowing new younger miners to participate in a computer application training where they can experience the environment, participate in and rehearse work tasks, and experience consequences while being in charge of their training can aid in effectively training this group of miners.

Other future work besides navigation studies and a performance-based evaluation will explore other scenarios in a task-based setting. This can be used to create advanced training sessions involving advanced maintenance issues, other safety issues, and procedures. The same methods and framework used to create the prototype application can be employed for similar sessions.

If a VR safety training application for surface conveyors is successfully implemented into the industry and is proved as a successful method for training young miners similar application can be developed to offer flexible, safe training for other pieces of machinery commonly used within the mining environment.

It is hoped that this research can aid in the safety training of new employees and the continued training of experience employees as required by MSHA. The application is not developed to replace current training methods but fill in the gap of experiential training that currently only exists as on-the-job training which is important for new employees training but also inherently dangerous for someone who is not familiar with all the proper procedures and policies of an actual working environment. To aid in the success of the program much emphasis was put on industry input in the development of the application and industry feedback through the evaluation of the application. If the application fits the industry's training needs it is more likely to be accepted as a valuable piece of their overall training program. It is with the aid of the industry that a program that fits their needs, is easy to use, and is easy to develop and modify can be offered as a potentially valuable tool to improve training and ultimately eliminate injuries and save lives.

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9. APPENDIX

9.1 Appendix A – Industry Feedback Questions and Comments

During each review session the meeting attendees were presented with the following questions to stimulate discussion about the information presented within the prototype during the review sessions:

1. Is the scenario of the session accurate for something an employee might have to do?
2. Do the questions asked have the proper answers?
3. Are the scenarios for possible solutions to hazards reasonable?
4. Are the processes depicted accurate?
5. Are any of the processes or actions misrepresented?
6. Was any of the information presented difficult to understand?

Some general questions were also asked about the concept and framework of the prototype application:

1. Would this fit your training needs and how can it be improved to better fit your training needs?
2. Can an application like this be a valuable addition to your current training material?

This table includes the full list of comments that the research team received from the industry feedback sessions. Comments in *italics* were suggestions for future scenarios.

Station	New or Existing	Comment	Meeting
1		Material Accumulation Hazard	
1		What is wrong with this?	
1		How would you fix this hazard?	
	E	Mention root cause for the hazards in the right answer	L1
	E	<i>Change position of material accumulation to tail pulley</i>	L1
	N	You can hose out the accumulation while the belt is running. With guarding you can shovel out the material without locking and tagging out while it is running.	L1
	N	Find out what is causing the accumulation and fix that problem	L1
1		What would you need to do to lock-out & tag-out?	
1		Missing Return Idler Guarding Hazard	
	E	Put a person or Indicate ht (dimension line) where return idler is unguarded	L1
	E	Mention 7' or reachable in Return idler text.	L1
	N	<i>Possible question – "Should this be guarded"</i>	L1
	N	<i>Possibly make the guarding loose so they would be more tempted to just push it up or tighten it</i>	L1
	N	<i>Place guarding on the ground</i>	L1
1		What is wrong with this?	
1		What would you do to fix this hazard?	
1		Broken Railing Hazard	
	E	Fix it now in addition to just recognizing the hazard. Barricading access to that area	L1
	E	Use of temporary cables and yellow tapes (include as part of answers)	L1
	N	Most important to deny access the hazardous area unless if wearing a harness and tied off	L1
	N	Rail can be fixed while the belt is running	L1
	N	Show the yellow tape when answering the question, tape needs to be placed at both ends to prevent access to the area	L1
	N	It is not a good idea to leave the yellow tape too long, there should be plans to fix it	L1
1		What is wrong with this?	
1		What would you do to fix this?	
2		<i>Start the belt</i>	
2		Turn on power at breakers	
2		Sound alarm in tower	
	E	Needs to wait after alarm sounds to give people time to move out of way, no more than 30 seconds as required by MSHA	L1
	N	Operator needs to observe visually if anyone is there around the belt before starting the belt. Maybe add a person in the scenario to help make the point of clearing the area. Make person visible from the tower.	L1
	N	Make sure the area is clear before starting the belt or sounding the alarm	L1
	N	<i>Show counter to make sure the belt is started within 30 seconds</i>	L1
2		Start belts	
3		Ensure belt is working properly	
3		Locate the broken idler	
	N	Extinguish fire first so belt doesn't start on fire and then turn off the belt. Smell the fire add as a point in text. If only smelling friction of hot rubber, then shut down the belt and fix the idler.	L1
4		Replace broken idler	

	N	Need guards on the return idlers near cat walk at 12' ht. (or raise catwalk)	L1
4		Turn off BC3	
4		Turn breaker BC3 off	
4		Lock-out and take key	
	N	Make User remove key	B1
	E	tag is missing on the lock	L1
4		Fix broken idler	
4		Click to remove guarding	
4		Click to replace idler	
4		Click to replace guarding	
4		Unlock breaker BC3	
4		Turn on breaker BC3	
4		Turn on conveyor BC3	
G	N	Ask questions to user	B1
G	N	Need to show more breakers – one for each piece of equipment	B1
G	N	Need to label belts and breakers	B1
G	N	Need control tower/room	B1
G	N	Instruction – Reminders of what task is being completed	B1

9.2 Appendix B – Usability Survey Statements and Results

Clarity of Instructions – Statements 1 – Average 3.23

<i>Clarity of Instructions – Rates of Agreement for Statements 1</i>				
<i>Strongly Disagree</i>	<i>Disagree</i>	<i>Neutral</i>	<i>Agree</i>	<i>Strongly Agree</i>
0%	15%	8%	23%	8%

1. The **instructions** were clear on what to do. (*Average Response 3.23*)

Please rate the instructions dealing with how to complete the tasks and identify hazards.

Ease of Navigation – Statements 2-3 – Average 3.42

<i>Ease of Navigation – Rates of Agreement for Statements 2 - 3</i>				
<i>Strongly Disagree</i>	<i>Disagree</i>	<i>Neutral</i>	<i>Agree</i>	<i>Strongly Agree</i>
11%	23%	4%	35%	27%

2. The mouse controls were easy to get used to. (*Average Response 3.08*)

3. The keyboard controls were easy to get used to. (*Average Response 3.77*)

Clarity of Objectives – Statements 4-6 – Average 3.62

<i>Clarity of Objectives – Rates of Agreement for Statements 4 – 6</i>				
<i>Strongly Disagree</i>	<i>Disagree</i>	<i>Neutral</i>	<i>Agree</i>	<i>Strongly Agree</i>
5%	16%	18%	37%	24%

4. The **objective** was easy to understand. (*Average Response 3.92*)

Objective: the scenario that was created “Pre-shift inspection...”

5. It was easy to navigate through the session in order to complete the desired tasks. (*Average Response 3.23*)

6. The **tasks** I had to complete were clearly understood. (*Average Response 3.69*)

Tasks in this session included identifying hazards, starting the belt, and replacing broken component.

Understand Ability of Information – Statements 7-11 – Average 4.03

<i>Understand Ability of Information – Rates of Agreement for Statements 7 – 11</i>				
<i>Strongly Disagree</i>	<i>Disagree</i>	<i>Neutral</i>	<i>Agree</i>	<i>Strongly Agree</i>
0%	10%	9%	45%	36%

7. The **hazards** are easily recognizable. (Average Response 3.77)

Hazards in this session included the spilled material, missing idler guard, and broken rail.

8. The questions that are asked with each hazard were clear. (Average Response 4.23)

9. The possible answers were clearly written and easy to understand. (Average Response 4.62)

10. It was clear what the animations for selecting a wrong answer were trying to show. (Average Response 4.00)

11. The **lock-out, tag-out process** was easy to complete. (Average Response 3.54)

The lock-out, tag-out process deals with the entire process of turning off the breaker, picking up the lock, placing the lock, taking the key, and placing the tag.

Ease of Completing Tasks – Statements 12-13 – Average 4.00

<i>Ease of Completing Tasks – Rates of Agreement for Statements 12 – 13</i>				
<i>Strongly Disagree</i>	<i>Disagree</i>	<i>Neutral</i>	<i>Agree</i>	<i>Strongly Agree</i>
0%	8%	27%	23%	42%

12. It was easy to turn on the belt (sound the alarm and turn the lever). (Average Response 4.23)

13. It was easy to find and replace the broken component on the belt. (Average Response 3.77)

9.3 Appendix C – Usefulness Study Survey Questions and Responses

1. What are some advantages of a typical training method you are familiar with over the reviewed application?

- Typical methods are more common so most people are familiar with those methods of learning and it does not require interaction with a computer.
- There is an instructor who is telling you exactly what you need to know, who you can interact with, and who can answer questions.
- Typical training accommodates more learning styles and allows for covering learning disabilities.

2. What are some of the advantages of the reviewed prototype application over the typical training methods?

- That the VR application allows personal involvement, interaction with the training in a (close to) real world environment with consequences and feedback to actions.
- The VR allows for a wide range of information material.
- The VR allows the user to rehearse tasks and not just have someone tell you about it.

3. What features of the reviewed application do you see as the most beneficial for learning the training material?

- The user is performing the task in the required sequence rather than just looking, listening, or reading about it.
- It allows for the trainee to interact with the environment to perform a job hands on. Testing the trainee of their ability to perform the task in real life.
- It allows for the demonstration of cause/effect situations and shows what would likely happen in real life if the required process was not followed

4. What challenges/ shortcomings do you see in learning the training material using the reviewed application?

- Usability for the older generations or individuals who are not familiar with computer/video games and their navigation.
- Applying the material for all education and computer skill levels so that the entire industry population can use it.

5. Do you think the proposed training application is an effective way to learn the material? Why or why not?

- That the VR gives them an interactive experience where they could rehearse processes safely.

- That the users were able to view processes step by step in the instructional-based session and then try them out in the task-based module.
- That the interaction gives them control over their training.

6. Which method of training do you perceive as a more effective way of learning? Why?

- 5 yes
 - It allows for an interactive, self controlled training
 - The user can view the process and rehears process and not just read about it. They can experience the consequences without the danger of a real life environment
- 3 no
 - Allows a personal interaction with an individual of experience who can answer questions
 - The typical training methods allow for learning by individuals who do not need to be computer literate or learn better in a classroom setting.