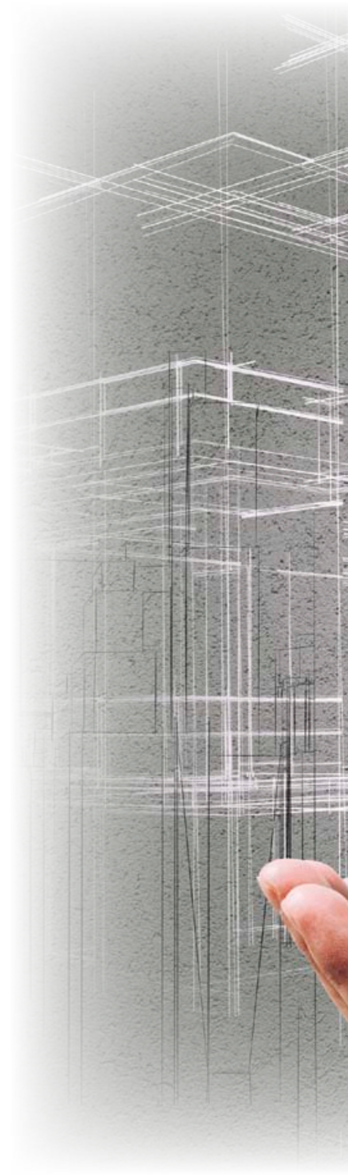

Safety Training
Enhancing Outcomes Through Virtual Environments

By Shoji Nakayama and Ge Jin

Organizations use online training to address various hazards that produce occupational injuries and illnesses. However, online training is challenged to reproduce the hands-on element that is critical to adult learning. Since most adults learn better when they manipulate objects in a real environment, a virtual environment can help replicate the physical training environment while maintaining effectiveness.

This pilot study focused on the use of 3-D virtual safety exercises to enhance online training. In these simulations, workers interacted within a virtual environment that simulates a live, hands-on environment, but without risk. Results indicate that participants in a virtual environment retained as much information as peers trained in the mechanical lab environment. These results support the feasibility of using a virtual environment to enhance online safety training.

IN BRIEF
- Some organizations have shifted safety training to online delivery. However, since most adults learn better with hands-on experience, online training can be less effective.
- This study focused on the development of a 3-D virtual safety training program that simulates a live hands-on environment.
- Tests of the program showed that participants gained as much information as in a live environment.

The Need for Occupational Safety

According to Bureau of Labor Statistics (BLS, 2013), the number of fatal work injuries in the U.S. in 2012 was the second lowest since 1992, when the Census of Fatal Occupational Injuries was first conducted. Still, the figures are sobering—3 million industrial injuries and 4,383 fatalities (BLS, 2013)—largely because many of the incidents were preventable. Some sources estimate that approximately 95% of all workplace incidents are preventable by someone at the employee, supervisor, manager and/or corporate level (New York State Department of Transportation, 2004). Although definitions of preventable incidents vary, the agency estimated this percentage through a peer-review process led by safety professionals in the region. OSHA (2007) officials have made similar observations.

OSHA (2008) notes that "recent estimates place the business costs associated with occupational injuries at close to $170 billion—expenditures that come straight out of company profits." In the U.S., occupational injuries and illnesses cost employers more than $53 billion a year in workers' compensation and medical costs (OSHA, 2012).

This amount does not include indirect costs such as lost productivity, overtime, fines, employee retraining and/or replacement and investigation costs. These costs can double or triple the total. According to Lazzara, each $1 spent on direct costs generates $3 to $5 of indirect costs. For example, an incident with direct medical charges and compensation may cost an organization $15,000, but it will likely cost between $45,000 and $75,000 more in indirect costs (Liberty Mutual, 2008). Furthermore, Leigh (2011) estimates that in 2007 direct and indirect costs of fatal and nonfatal injuries in the U.S. were approximately $250 billion.

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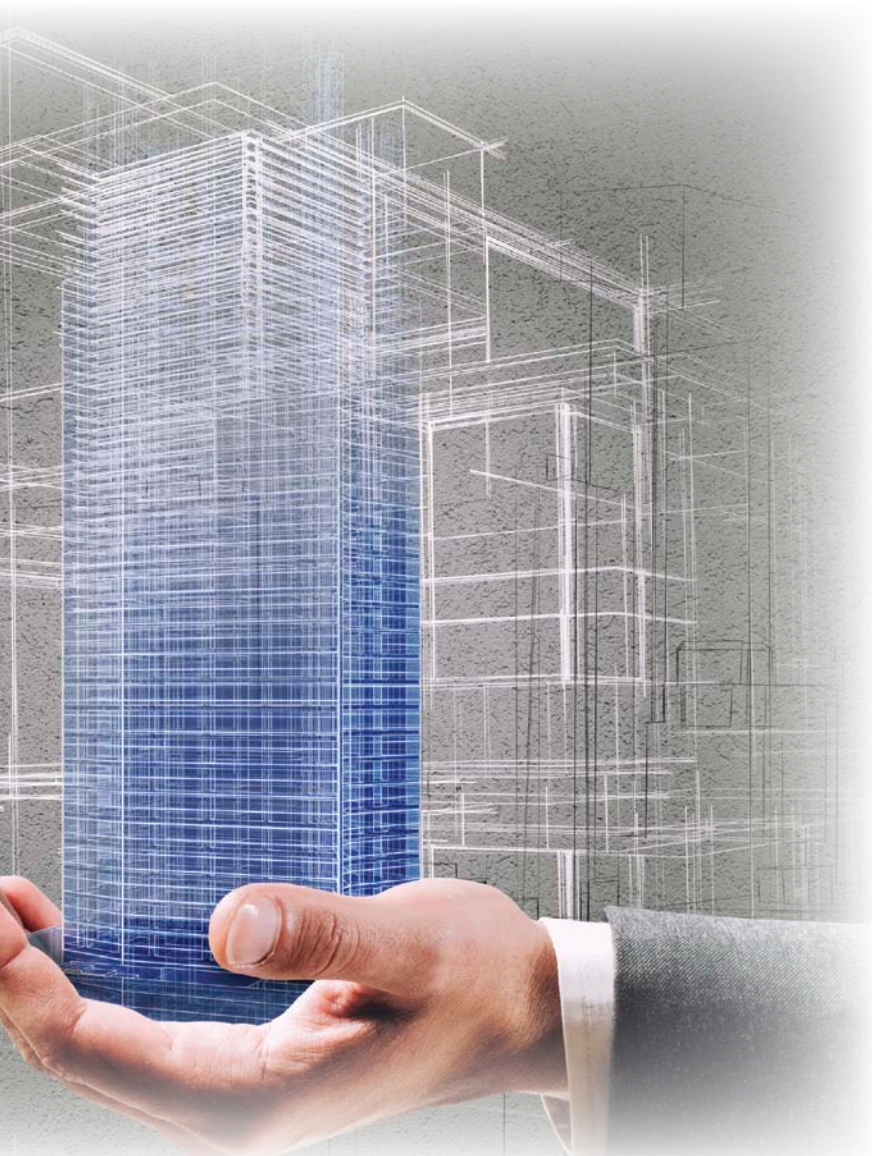

Hazard Control Methods

OSH professionals aim to control hazards and reduce incident costs. In designing such prevention, many use the hierarchy of controls. The most effective means of control is designing out hazards (which includes avoidance, transfer and substitution); next are engineering controls, awareness devices, administrative controls, training and PPE.

While designing out hazards is ideal, training, in conjunction with other controls, can be an effective way to protect employees from harm. Traditional safety education typically includes in-person lecture with a limited amount of hands-on exercises for trainees. In some cases, materials such as DVDs and streaming videos are incorporated to enhance participants' understanding and awareness of the topic.

However, most adult learners acquire knowledge and skills better when they participate in training and get their hands around a piece of equipment (Torres, 2007). Physical and emotional interaction are essential elements to improve learning, especially in the OSH field. A study conducted at Kansas State University (K-State Research & Extension, 2007) shows that adults learn best when they are active partners in the learning process. The researchers urge educators not to lecture adult learners but rather involve them in discussions, problem solving and hands-on activities. Anzalone, Poudel and Vincent (2005) also report that "hands-on activities and challenge tests enhanced students' interest, motivation and ability to think critically about contemporary environmental issues in the region" (p. 10).

Shift of Safety Training Delivery Method

Due to technology advancements and the 2008 economic recession, many organizations have transitioned from in-person, hands-on training to online training (Allen & Seaman, 2010). Based on an analysis of industry sectors, Peters and Lloyd (2003) consider online delivery to be useful in OSH training. In the same study, employers indicated that online training would be most suitable for technical skill training such as occupational safety, regulatory compliance and new technologies. However, while online training offers several advantages, it does not readily accommodate the hands-on experience that is crucial to adult learning.

New Training Delivery Methods Using 3-D Virtual Environment

This pilot project aimed to streamline safety training while maintaining its effectiveness. Specifically, the goal was to experiment with 3-D virtual safety exercises that would bypass the real-life dangers found in the workplace while effectively teaching trainees how to avoid them. An ideal virtual reality (VR) environment would allow participants to immerse themselves into a realistic environment, interact with it, identify hazards and acquire application-oriented experience safely.

VR technology can be traced back to the late 1960s, when Sutherland (1968) and his student took the remote reality camera vision systems into VR with computer-generated images. This led to the development of flight and medical simulators. Various researchers have shown that medical simulation helps novice users (i.e., medical students) gain essential knowledge of surgical practices. Furthermore, virtual education and training software, such as training based in VR, medical simulators and virtual rehabilitation tools, have shown great potential in industry and the military (Delaney, 2000; Nunes & Costa, 2008).

Training in a simulated virtual environment also reduces the risk of injury or loss of life for trainees.

Adults acquire knowledge and skills better when they participate in training and get their hands around a piece of equipment.

Figure 1

3-D Virtual Environment Example

This pilot test presented 3-D virtual safety exercises that would bypass the real dangers found in the workplace while effectively teaching trainees how to avoid them.

Recently, virtual environment and gaming technologies have been applied to safety education in mining, construction and manufacturing industries (Orr, Mallet & Margolis, 2009).

VR has also been shown to successfully teach fire-safety skills to younger people. Smith and Ericson (2009) used VR to simulate situations that are too dangerous to practice in real life. A paired *t*-test indicated significant improvement in test scores after the VR fire-safety training ($t = 4.74$, $p = .0001$). Thus, the literature suggests that VR-based learning is effective in teaching people to avert danger.

Purpose of Pilot Study

The pilot study aimed to teach safety effectively through 3-D virtual exercises. After discussions with industrial safety professionals, the researchers selected operation of a pedestal grinder as the task. Specific safety-related issues in the manufacturing industry were identified based on a simple gap analysis between industry needs and safety-related topics, and machine guarding was among OSHA's top 10 most-cited violations in 2013. In this study, the research team tested trainees' learning outcomes in three groups: lecture only, lecture with physical laboratory and lecture with the virtual exercise.

Development of the 3-D Virtual Safety Exercise

To develop the virtual safety exercise, the research team faced three major technical challenges: 1) 3-D modeling of a pedestal grinder and virtual environment; 2) dynamic simulation of machine/equipment operations; and 3) identification of potential hazards and regulatory violations within an immersive, interactive 3-D virtual environment.

Creation of 3-D Grinder Model & the Virtual Environment

The virtual environment was created using the Unreal Development Kit game engine (Epic Games, 2013). This game engine allows researchers and academic institutions to develop games and interactive virtual environments for educational purposes and redistribute them without licensing fees. To create the 3-D virtual environment, one must also create 3-D models for surrounding mechanical equipment and PPE. For 3-D modeling purposes, the researchers took photographs of a grinder, other mechanical equipment and PPE from different viewpoints. Then, these photos were brought into 3-D modeling software as reference images.

Next, the researchers measured (in inches) the equipment, and input proper scale and unit data into the software. Finally, commercial 3-D modeling software was used to transform the real-world object into a 3-D model. The photos from multiple viewpoints were projected onto the 3-D grinder model to increase the visual realism of the environment. A similar approach was used to convert other virtual components.

The grinder model and other virtual components were merged into the virtual environment using the 3-D game engine. The resulting virtual environment would allow trainees to interact and immerse themselves in a realistic environment without the hazards of grinding. In addition, necessary protective measures could be easily added within the virtual environment.

To enhance trainees' understanding of hazards associated with grinder operation, the environment included 3-D models of both essential and irrelevant PPE such as goggles, masks, earplugs/earmuffs, gloves and boots. In addition, two human models were incorporated to illustrate additional operator hazards such as wearing a necklace, tie, long skirt or other loose objects. Additional mechanical and storage equipment were also included to create an environment as close to a real laboratory environment as possible.

Simulation of Grinder Operations in Virtual Environment

Once a trainee launches the virtual safety exercise, a screen pops up to provide detailed instructions for interaction and navigation. Each user can "walk" inside a virtual environment to operate the virtual grinder by following all safety guidelines and rules. In this exercise, the user must first select the correct PPE, then must identify and correct hazards that affect an operator.

For this study, trainees practiced three major safety procedures: 1) selecting eye protection; 2) judging the distance between the wheel surface and the work-rest; and 3) judging the distance between the wheel surface and tongue guards. To simulate potential hazards related to each procedure, the virtual grinder was separated into components so that each could be operated independently. Potential hazards and appropriate corrective measures were programmed into the exercise.

In this exercise, a trainee moves a cursor over a specific hazard(s) and clicks a mouse. Once the trainee selects a predetermined hazard within the virtual environment, an interface pops up that allows him/her to select a corrective action(s). The selected action is then compared with the preprogrammed action sequences inside the game engine.

If the trainee has correctly selected PPE, identified all the safety hazards and adjusted guarding components inside the virtual environment, immediate feedback appears (Figure 1). Otherwise, the trainee receives a failure notice that indicates s/he has not followed the correct procedures. However, trainees can retake the training until they correctly identify all of the safety hazards in pedestal grinder operation.

Pilot Study Using a Virtual Safety Exercise

A pilot study was conducted from 2010 to 2011 to validate this 3-D safety exercise. Participants were students enrolled in an OSH course, and the population included both traditional and nontraditional students. A total of 89 students from four course sections volunteered to participate (anonymously), and each student was randomly assigned to one of the three training delivery methods. Those individuals who were willing completed a survey/test, while others left the survey/test sheet blank.

All sections received the same lecture on safe grinder operation (a PowerPoint presentation by one of the authors, along with photos). The lecture showed and explained potential hazards and appropriate controls to avoid these hazards. Participants in one section received only the lecture. The second section received the lecture and conducted an exercise in the mechanical lab on campus during which they viewed and experienced how to operate a grinder safely. Students in the third section received the lecture plus a 3-D virtual laboratory exercise. The postdelivery assessment was completed by 22 students in the lecture-only section, 16 students in the lecture/physical lab section and 20 in the lecture/virtual lab section.

All participants were assessed on their understanding of specific hazards and safety measures related to grinder operation. Each section's assessment was conducted 1 week after its training. The effectiveness of this experiential learning was assessed by testing whether trainees could identify mechanical hazards and select proper controls to prevent injuries while using a grinder. Questions for this pilot study were taken directly from "The Daily Grind: Test Your Knowledge on Grinder Safety" (**http://bit.ly/1s1SS7s**; MANCOMM, 2010).

Validation of Developed Virtual Safety Exercise

Results indicate that in the 3-D virtual environment, participants learned more than did their peers in the lecture-only group. Furthermore, the virtual safety exercises taught as much information as did the lecture/physical lab method.

Table 1 summarizes assessment results for each section. On average, the lecture-only section scored 47.72%, the lecture/physical lab section scored 68.06%, and the lecture/virtual exercise section

Table 1

Delivery Method & Assessment Scores

Delivery method	Sample size	Assessment (quiz) average score	Median score	Max. score	Min. score	*SD*	*F*	Sig. ($p < .05$)
Section 1: Lecture only	22[a]	47.72%	52.78%	100%	0%	0.3065	14.94142	.0000066
Section 2: Lecture with physical laboratory	16[a]	68.06%	69.45%	88.89%	27.78%	0.1919		
Section 3: Lecture with virtual laboratory exercise	20[a]	86.11%	88.89%	100%	55.56%	0.1306		

Note. *[a]The number of students who took the voluntary quiz. Does not reflect the number of students in the course.*

Results indicate that in the 3-D virtual environment, participants learned more than did their peers in the lecture-only group. Furthermore, the virtual safety exercises taught as much information as did the lecture/physical lab method.

Table 2

Tukey-Krammer Test Between Three Delivery Methods

Comparison	Absolute difference	Standard error of difference	Critical range	Results
Lecture only versus lecture with physical laboratory	20.32877	5.28836883	18.03333771	Means are different
Lecture only versus lecture with virtual laboratory exercise	38.38317	4.972783791	16.95719273	Means are different
Lecture with physical laboratory versus lecture with virtual laboratory exercise	18.0544	5.398555015	18.4090726	Means are not different

Note. $p = .01$

earned the highest assessment score of 86.11%. An ANOVA-F test showed a significant difference (p = .0000066) between three delivery methods.

Physical and emotional interaction are essential elements to improve learning, especially in the OSH field.

Furthermore, a Tukey-Krammer test with significance level .01 confirmed that lecture with virtual laboratory methods and lecture with physical laboratory methods outperformed the lecture-only method. The test also found no significant difference between lecture with physical laboratory and lecture with virtual laboratory methods, with significance level of .01 (Table 2).

The results may raise a concern that the VR was designed similar to the quiz and so biased to yield higher scores. However, the virtual safety exercise was designed as an open-ended virtual environment that contained three subexercises/components. Participants were to experience these three components before they were notified of their learning result. In virtual safety exercises, participants were exposed to both correct and incorrect choices; therefore, they were not guided toward any correct answers. The overall result is reported as pass or fail. If someone fails, the program only highlights which component(s) was failed, it does not provide the correct answers; in other words, the student must have comprehensive skills to be successful. In short, the study results support the use of the 3-D virtual safety exercise to enhance participants' learning.

Conclusion

While online training can be used as an alternative to traditional in-person delivery, companies must consider incorporating hands-on components to make online training effective. The researchers created a 3-D virtual environment in which participants could interact with various work components. In this study, the online safety training element operated inside a virtual environment to provide hands-on experience while protecting participants from harm. The study results indicate that the safety exercise was as effective as a safety demonstration in the physical laboratory; therefore, it could be used as a substitute for hands-on exercises.

Safety training institutions with online capabilities might explore incorporating 3-D virtual exercises. Such exercises eliminate physical injuries to trainees, and they can be easily adapted to deliver virtual safety-related experiences on multiple platforms. The desktop-based 3-D virtual environment can also be modified into a web-based interactive application. However, further study is needed to verify whether these web-based experiences also enhance students' learning in a risk-free environment. **PS**

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