Improving Students’ Learning Outcomes in Safety Education through Interdepartmental Collaboration

Shoji Nakayama, Ph.D. and Ge Jin, D.Sc.
Purdue University Calumet
Hammond, Indiana

Abstract

It is critical to learn the theory to work safely. However, it is also important to learn how to apply such theories into the workplace. In addition, adults learn best when they are active partners in the learning process. The authors emphasize not to lecture adult learners but rather, get them involved in discussions, problem solving and hands-on activities. To assist this effort, Purdue University Calumet (PUC) has initiated interdepartmental collaboration between Organizational Leadership and Supervision (OLS) and Computer Information Technology and Graphic (CITG) departments to develop simulated virtual environment to enhance hazards identification and mitigation skills in safety related courses. A pilot study was conducted in three sections of Occupation Safety and Health course receiving the same lecture on commonly used equipment in manufacturing industry, “abrasive wheel.” One section received only lecture component; second section received lecture with laboratory exercises; and third section received lecture with developed simulated virtual environment. On average, the students who went through simulated virtual environment attained higher assessment scores compared to the students who went through other two teaching methods: lecture only and lecture with laboratory exercises.

Introduction

Interactive experiential learning approach has been mentioned as one of the essential elements to improve student learning, specifically to the safety and health discipline. Utilizing a virtual learning environment will convert the way students learn and enhance their learning compared to conventional laboratory based learning. To achieve this, authors have collaborated between two departments within the institution.

The goals of this interdepartmental collaborations were to: (1) develop virtual safety exercises to enhance student learning in the field of safety and health as related to manufacturing and (2) measure the change in student learning outcome through enhancing the current safety curriculum by adapting and implementing the newly developed virtual safety exercises.

Safety, health, and environmental issues are important components for corporate sustainability. According to Friend & Kohn, companies throughout the United States have seen over 5,000 on-the-job fatalities every year for the past several years. According to the Bureau of Labor Statistics (BLS), a total of 5,488 fatal work injuries were recorded in the United States in 2007. Although this number is a preliminary count, the rate of fatal injury for U.S. workers was 3.7 per 100,000 workers. Moreover, 90% of the fatal work injuries have occurred among workers in
private industry. According to National Occupational Health and Safety Advisory Committee, the largest shares of injuries were in the manufacturing sector (20%), the healthcare and social assistance sector (16%) and the retail trade sector (15%) 

According to OSHA, “Recent estimates place the business costs associated with occupational injuries at close to $170 billion – expenditures that comes straight out of company profits” 6. As Lazzara indicated, every dollar spent on direct costs generates three to five dollars of indirect costs 7. For example, if an accident with direct medical and compensation costs an organization $15,000, it will likely cost between $45,000 and $75,000 more in indirect cost. As indicated in the Safety Bulletin issued by the State of New York, approximately 95% of all workplace accidents are preventable by someone at the employee, supervisor, manager and/or corporate level 8. This is also supported by an OSHA area director in Appleton, Wisconsin who had indicated “Injuries such as amputation and fatalities from accidents are preventable.” 9

Academic institutions need to address the fact that human lives are being lost, people are being injured and properties are being damaged from events that are otherwise preventable. As most of these “accidents” are preventable, institutions can support, eliminate, or reduce these accidents by educating students to apply their theoretical safety processes through incorporation of experiential learning. The virtual safety laboratory exercises that were developed under this collaboration will help students who will be working in industry. Gaining safety related knowledge is important, but application of safety knowledge is essential in this field. Laboratory based technology programs traditionally provide a set of experiments with the expectation that the meaningful learning takes place upon completion of these experiments.

Virtual Reality (VR) environment will be used to enhance student learning as well as making the safety related topics more appealing to various groups of students. Research has shown how you look, including self-imaging, and what you do physically and emotionally in a virtual world can be drastically different from the physical world 10. Given that self image is unique to virtual environments because it can be controlled in a different way than in traditional in-classroom setting, and will allow wider participation.

This paper would help to provide technical information to who may have limited access to the skills and knowledge required to develop such venue. Technical materials needed for this venue can be obtained through the use of VR exercises students have access to, regardless of their demographic background.

The goal of this paper is to provide a practical alternative learning opportunity for students who find accessing traditional learning environments difficult, limiting, or lacking in facilitating individual needs. In accompaniment with the United States Federal Communication Commission National Broadband Plan, the immersive and distance-learning outcomes of this paper can be made accessible to various populations whom otherwise may not be able to access or adapt to traditional learning environments 11. In addition, students with impairments and learning challenges may also benefits from this paper.

**Importance and Justification of Hands on Learning in Safety Education**
Traditional safety education mostly includes face-to-face lectures with a limited number of industrial field trips. In some cases, movie clips and various multimedia are used to enhance student’s understanding and awareness of safety related topics as studied in a classroom. However, it is also important to note that adult learners retain knowledge better by demonstrating what they have learned in a classroom setting. This is supported by Torres, who indicated an importance of trainees’ involvement through physically and emotionally in the safety learning process regardless of the training method. Terry Krug, a senior safety and health instructor with the Occupational Safety and Health Administration (OSHA) Training Institute (OTI) also stated that trainees had better content retention when they attended a workshop or got their hands around a piece of machinery. A study conducted by Waehrer and Miller suggested that safety training increases reporting of injuries as well as safety on days-away-from-work injuries. In addition, this study indicated that safety training appears to be more effective in preventing severe injuries. This concept applies not only in the training but also within academic institutions. It is critical to learn the theory to work safely however, it is also important to learn how to apply such theories into the workplace or work environment. In addition, adults learn best when they are active partners in the learning process. The authors of this paper emphasize not to lecture adult learners, but rather get them involved in discussions, problem solving and specifically interactive experiential learning activities through virtual safety exercises.

The virtual safety exercises that were developed by this interdepartmental collaboration made it possible to emulate desired industrial settings for students in a desktop VR exercises without leaving the campus or their home. Virtual safety exercises presented in this paper will enhance student ability to apply lectured material safety education. Students will be exposed to interactive experiences and will be encouraged to make appropriate safety decisions in industrial settings.

**Justification of Reasons for VR**

The virtual reality training applications and serious games have been growing in market size and diversity in the last decade. The serious games market in 2007 was estimated to be around $400 million. Based on IDATE (The European Institute for Audiovisual and Telecommunications) review on serious game market, it currently generates 1.5 billion EUR in revenue around the globe, and that by 2015 sales will reach 10 billion EUR. With the increased use of VR training simulators, numerous researches have been conducted to evaluate the effectiveness of the VR simulators and simulator based training. One of the most widely evaluated areas in simulator based training is medical simulators. This is because the effectiveness of the simulator based learning is directly related to the result of future clinical outcomes of the patients. A number of medical education software was evaluated based on the score of the 2nd year undergraduate students performing a set of given tasks. Rees et al. evaluated the VR simulator in teaching pre-clinical operative dentistry to perform Class I cavities and Class II cavities. The evaluation result of simulator is generally positive in undergraduate education. The study of comparing the effectiveness of two laparoscope simulators demonstrated that naïve subjects trained on a virtual-reality trainer performed better on live surgical tasks in a porcine model. A research has been conducted to compare the physical model and virtual reality simulator for laparoscopic surgery training. The results showed that the physical training system was more sensitive to the experience levels of the subjects than the virtual system. Generally, medical VR simulators are
especially effective for novice users such as medical students in gaining essential knowledge on hands-on surgery.

An application of virtual reality tool within academic institution is important to enhance students' learning, because students have different level of learning ability. Due to limitation of access to the physical lab, desktop VR is a more feasible option for academic institutions with limited space and budget. Desktop VR is feasible and has more potential because the number of online courses throughout the country has increased. In this paper, we evaluated the effectiveness of the virtual safety exercises with students in three sections of Occupation Safety and Health course (OLS 33100). Students in three sections received the same safety lecture on commonly used equipment in manufacturing, “abrasive wheel.” Students in section one received only lecture of “abrasive wheel.” Students in the second section received lecture along with physical laboratory visit. Students in the third section received lecture, as well as hands-on experience using developed virtualized safety exercises. The mean score within the controlled timeframe will indicate the effectiveness of the developed virtual safety education software.

As PUC is one of the regional campuses, it traditionally attracts students within 50 miles radius from the campus who typically work full-time or part-time. The institution articulated the importance of distance education as a part of the university’s strategic plan. This desktop VR exercises would therefore accommodate not only commuter students but also students who reside outside of commuting distance. The development of desktop VR safety exercises would therefore help enhance online students’ learning.

Collaboration Process

During this collaboration effort, each faculty member shared his specialization that could contribute to the development of a laboratory that would benefit various departments. After the meeting, an idea of converting physical laboratory exercises into virtual platform was derived. Upon discussion, faculty members from various program/departments brought in the strength in which we could contribute to make this project happen. Since other programs beside OLS also offer online classes, they also needed a laboratory which enhances their curriculum. Furthermore, the group has decided to develop an environment where various safety training scenarios can be reviewed without changing locations. The group then decided to discuss further, solidify this process, and execute the project.

Development of desktop VR safety exercises

The development of virtual safety exercises consists of three major technical components: (1) three-dimensional (3D) modeling of equipment, (2) dynamic simulation of machine/equipment operations, and (3) identification of potential hazards and safety violations within a virtual environment. After selecting specific equipment typically seen in manufacturing environment, “abrasive wheel”, the team prepared an execution plan. First, students from Engineering Technology (ET) worked together with faculty members from participating departments. They took pictures of “abrasive wheel” equipment from several viewpoints for 3D modeling and texturing purposes. Second, pictures taken by students were converted into 3D model with the support from faculty members. Third, faculty members from CITG and OLS discussed how to
visualize 3D models in the desktop VR safety exercises. Furthermore, hazards were indicated and proper corrective measures were programmed into the desktop VR exercises. These developed exercises allow students to visually identify hazards and be able to correct such hazards accordingly.

The typical hazard identification in “abrasive wheel” includes the distance between surface of wheel and the work rests, the distance between surface of wheel and tongue guards, and the placement of eye shield. Then, the equipment is broken into separate components that can be operated independently to show those hazards. This way, these components can visually illustrate the hazards and be virtually corrected in desktop VR.

The 3D grinder model was unwrapped in UV texture coordinate to map the texture from photos. The UVW Unwrap in 3D Studio Max has been used to unwrap the polygons to match with the real photos (Figure 1). To allow the students interact with virtual safety environment and enhance hands-on learning experience, we also modeled personal protective equipment (PPE) including goggles, masks, ear plugs, gloves and boots (Figure 2). Two human character models were created to illustrate the safety hazard in wearing necklace, tie, and long skirt (Figure 3).

Figure 1. An example of visual conversion of grinder equipment
Figure 2. Modeling of PPE
Figure 3. Modeling of machine operator hazard
With the advances in game engine technology, virtual training system can better approximate the real-world experiences encountered by learners upon incorporating state-of-art game technologies in training modules. In this paper, we adopted Unreal Game Engine to create desktop VR safety exercises. The grinder model and other safety related components were merged into a VR game environment to be visualized and interacted for safety laboratory exercises. We modified the game engine to enable the student virtually inspect the 3D grinder model and interact within 3D virtual environment to correct hazard of the grinder. Furthermore, Kismet, a visual scripting tool is used to create the safety training exercises. Figure 4 shows a Kismet sequence that enable the student to adjust the distance between tongue guard and the grinder wheel.

![Figure 4. Kismet sequence of adjusting tongue guard position.](image)

**VR Safety Exercise Process**

Once the student launches the virtual safety exercise, a screen will pop up to introduce a detailed instruction as to how to interact and navigate in the virtual environment. Each student can walk inside a virtual machine shop to perform the given task: operate “abrasive wheel” equipment by following all the safety guidelines and rules. There are three types of tasks have been incorporated into the virtual safety exercise: (1) picking up correct personal protection equipment (PPE), (2) identifying and correcting hazards affecting machine operators, (3) adjusting the distances of tongue guard, work rest, and other machine guarding components on the grinder. If the student had correctly selected PPEs, identified all the safety hazards, and adjusted guarding components inside the virtual environment, a screen will pop up to congratulate the student passing the virtual safety exercise. Otherwise, a fail notice will pop up and indicate the mistakes that the student made in the hazard identification exercise. The student can retake the virtual safety exercise until he/she correctly identify all the safety hazards in grinder operation.
The desktop virtual safety exercises presented in this paper is using Unreal game engine, therefore it can be easily adapted to other institutions without sophisticated equipment. The 3D models and the virtual reality software discussed in this paper can be directly used by other institutions with minimal modifications. Moreover, this VR safety exercise allows students to learn the essential components without putting him/her in harms’ way.

**Outcome – Results**

During the 2010 – 2011 academic year, the authors conducted a pilot study with groups of students enrolled in three sections of the same course. The instructor used three delivery methods covering the same topic. Students in three sections of Occupation Safety and Health course (OLS 33100) received the same safety lecture on commonly used equipment in manufacturing, “abrasive wheel”: Students in section one received only lecture of “abrasive wheel.” Students in the second section received lecture along with physical laboratory visit. Students in the third section received lecture, as well as hands-on experience using developed virtualized safety exercises. The mean score within the controlled timeframe will indicate the effectiveness of the developed virtual safety education software.

Once students in each section fulfill required lecture and/or various supplemental delivery methods, students were assessed on the understanding of the subject using the quiz. The first group scored 58.64%, the second group scored 75.93%, and the third group using virtualized exercises received the highest assessment score of 82.01%. This pilot study supports the advantages of utilization of virtualized laboratory exercises in enhancing students’ learning. Table 1 summarizes the results of this study, which supports the benefits of utilization of virtualized laboratory exercises over “lecture only” delivery method in enhancing students’ learning. Furthermore, virtualized laboratory exercises allow students to retain information as good as the “lecture with physical laboratory” delivery method. The significance level was determined by the ANOVA F-test and the result was 0.002288.

<table>
<thead>
<tr>
<th>Delivery Method</th>
<th>Sample Size</th>
<th>Assessment (Quiz) Average Scores</th>
<th>Median Score</th>
<th>Max Score</th>
<th>Min Score</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 - Lecture Only</td>
<td>9*</td>
<td>58.64%</td>
<td>55.56%</td>
<td>100%</td>
<td>16.67%</td>
<td>0.2954</td>
</tr>
<tr>
<td>Group 2 - Lecture with Physical Laboratory</td>
<td>9*</td>
<td>75.93%</td>
<td>77.78%</td>
<td>88.89%</td>
<td>55.56%</td>
<td>0.1361</td>
</tr>
<tr>
<td>Group 3 - Lecture with Virtualized Laboratory Exercise</td>
<td>21*</td>
<td>82.01%</td>
<td>88.89%</td>
<td>100%</td>
<td>55.56%</td>
<td>0.1306</td>
</tr>
</tbody>
</table>

*This is the number of students took the quiz does not reflect the number of students in the course due to voluntary based quiz.

Some of the factors that would benefit those readers include: (1) the material developed under this paper could be used by educators and students anywhere as long as there is an internet connection and a computer, (2) materials developed under this paper will significantly enhance students learning by incorporating integrative experiential learning along with traditional lecture, (3) this approach will allow learning by students with special needs who may not be able to
experience hands-on laboratory, and (4) this desktop VR exercises would provide means for a low cost adaption at other institutions and organizations.

**Conclusion**

Based on this inter-departmental collaboration, we were able to derive with a method that would enhance students’ learning in the safety education. Utilization of desktop VR safety exercises has shown students’ improvement in test scores on hazard identification and control measures of “abrasive wheels”. In addition to aforementioned improvements, this inter-departmental collaboration also achieved following: 1) CSOL was able to acquire exercises that would enhance the student learning in the safety discipline, 2) CTIG students gained hands-on interactive VR programming techniques, and 3) Both involved departments were able to learn each other field of study in depth. The pilot study from this paper also provided the understanding of the importance of virtual laboratory exercises in online learning where physical laboratory is not accessible. From this paper, readers should be able to learn the importance of hands-on component within academic setting and how to develop such application. In addition, attendees will be able to understand how desktop VR technology supported students’ learning in hazards identification and control.

**Bibliography**


Biography

SHOJI NAKAYAMA, Ph.D. is an Assistant Professor of Organizational Leadership and Supervision in the Department of Construction Science and Organizational Leadership at Purdue University Calumet. He teaches safety and health related courses, and has environmental, health and safety related experience in automotive, airline, regulatory agency, printing industries, and telecommunication.

GE JIN, D. Sc. is currently an assistant professor in the department of computer information technology and graphics at the Purdue University Calumet. He was a postdoctoral research scientist at the George Washington University department of computer science, from 2007 to 2008. His research spans the fields of computer graphics, virtual reality, computer animation, medical visualization, and image guided surgery. He is a member of the ACM SIGGRAPH, MICCAI and SPIE.