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Game based learning for safety and security education

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ABSTRACT

Safety and security education are important part of technology related education, because of recent number of increase in safety and security related incidents. Game based learning is an emerging and rapidly advancing forms of computer-assisted instruction. Game based learning for safety and security education enables students to learn concepts and skills without the risk of physical injury and security breach. In this paper, a pedestal grinder safety game and physical security game have been developed using industrial standard modeling and game development software. The average score of the knowledge test of grinder safety game was 82%, which is higher than traditional lecture only instruction method. In addition, the survey of physical security game shows 84% average satisfaction ratio from high school students who played the game during the summer camp. The results of these studies indicated that game based learning method can enhance students' learning without potential harm to the students.

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1. INTRODUCTION

The advance of graphics hardware, high-speed internet, and the pervasiveness of mobile devices, have enabled various computer-assisted instruction (CAI) pedagogical methods. One of the most emergent and rapidly mutating forms of computer-assisted instruction is "game based learning." As its name suggests, this method uses computer games to immerse learners in a simulated game environment while experiencing it as real. Game based learning includes virtual reality games, web-based games, multi-user virtual environments (MUVEs), massively multiplayer online games (MMOs), and simulations [1]. To date, however, applying game based learning instructional methods to safety and security education has been limited [2].

2. IMPORTANCE OF SAFETY AND SECURITY

In 2017, 5,147 fatal work injuries and approximately 2.8million nonfatal workplace injuries and illnesses were reported [3]. In other words, 5,147 workers went to work to make a living and trying to enjoy life have become persons who never returned home. Injuries, illnesses and fatalities are not only pain and suffering of an individual, but it also affect their family, friends and co-workers.

In addition to those numbers, these incidents cost U.S. business between $150 and $170billion every year. In 2018, the total cost of work injuries cost U.S. business approximately $161.5 billion [4]. However, it's not that these cannot be prevented. Just because hazards exist, it doesn't mean people should get fatally

injured. As indicated by the State of New York Safety Bulletin, approximately 95% of all workplace accidents are preventable [5]. And this statement was also supported by the OSHA area director in Appleton, Wisconsin, who has indicated that injuries and fatalities from accidents are preventable [6].

OSHA estimated employers pay almost 1 billion dollars per week for direct worker's compensation cost alone. However, each company would pay both direct and indirect costs when an incident was to occur. Direct cost includes worker's compensation cost, medical costs and costs of legal services. And some of the examples of indirect costs include lost time, loss in earning power, cost of retraining a new workers who fills in for injured workers, loss of production due to an incident, failure to fill, and costs associated with lower employee morale and absenteeism to name a few. Generally speaking, every dollar spent on direct costs generates three to five dollars of indirect costs [7-9] Liberty Mutual gave an example that outlines this costs associated with an incident. They estimated that the hidden cost of $15,000 incident would be more than likely between $45,000 and $75,000.

Security has become one of the major topics for various organizations, because of the increase in the number of incident in the past several years. Over the past few years, a large number of fraud incidents have been committed, especially in the financial and healthcare sectors [10, 11]. Such security breaches not only result in substantial financial losses, but also greatly hurt the confidence of customers, business partners and stakeholders [12]. Physical security is the protection of personnel, hardware, software, networks and data from physical actions and events that could cause serious loss or damage to an enterprise, agency or institution. Physical security describes security measures that are designed to deny unauthorized access to facilities, equipment and resources and to protect personnel and property from damage or harm. Physical security involves the use of multiple layers of interdependent systems which include CCTV surveillance, security guards, protective barriers, locks, access control protocols, and many other techniques. More organization has started to develop and/or enhance their workplace violence programs. Depending on the size of an organization, safety professionals often take a responsibility of securing the organization's physical perimeters. Hence, security can be often listed as one of the safety professionals' job. The increasing demand for safety and security professionals requires collaborative efforts from government, industry, and K-12 and higher education institutions to attract, prepare, and train future cybersecurity professionals [13, 14].

3. GAME BASED LEARNING

Game-based learning shares the common features of entertainment games, while the primary purpose of game-based learning is education or training [15-17]. The objective of this study is to streamline safety and security education and keep them effective by experimenting with 3D game environment [18]. Specifically, the game-based learning would bypass the real-life dangers of the workplace safety and security while still effectively educate how to avoid them. An ideal game based learning environment would allow participants to immerse themselves into the environment, interact with it, identify hazards and security pitfalls, and acquire application-oriented experience safely. Recently, gaming technologies have been applied to safety education in mining, construction, and manufacturing industries [19]. This game may even successfully teach fire-safety skills to younger people [20]. In that study, game was used 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 ($t= 4.74$, $p = 0.0001$). Thus the literature suggests that game-based learning is effective in teaching people to avert danger.

The goal of safety and security education games was to streamline safety and security training yet keep it effective by experimenting with 3D virtual environment. Specifically, the goal is to bypass the real-life dangers of the workplace while it effectively teach how to avoid them. An ideal game would allow participants to immerse themselves into the "real-life" environment, interact with it, identify hazards, and acquire application-oriented experience safely [21].

There are several advantages and disadvantages of using games for safety training. Some of the advantages includes game allows participants to experience hazardous environment without putting them in any danger. It also give several advantages such as immediate feedbacks to trainees, good for training where participants would get exposed to those hazards where you cannot see. Some of the disadvantages include some people may get sick from the virtual environment, some older trainees may have hard time navigating through such technology environment and it could become expensive if one tries to envelope a company specific training.

4. RESEARCH METHOD

The research method for game-based learning in safety and security disciplines requires four components: 1) Topic identification, 2) 3D modeling of virtual game environment, 3) Game programming and 4) Assessment of learning.

4.1. Topic identification

The primary goal of this game based learning research is to: 1) raise general awareness of safety and security concepts for the students, and 2) help students to understand appropriate safety and security procedures. To achieve the game based learning objectives, safety game and physical security game have been developed.

a. Pedestal grinder safety game: The equipment and machine operation selected for this study was through discussions with industry professionals in the areas of Safety, Health and Environmental Management. Specific safety related issues in the manufacturing industry were identified based on a simple gap analysis between industry needs and safety related topics covered in engineering technology programs. One of the OSHA's top 10 most cited violations in 2019 was "machine guarding" [22]. As indicated by the safety academic advisory board members, a pedestal grinder is one of the dangerous machineries that many organizations have. Therefore, the authors had decided to develop the virtual safety exercise in 3D environment focusing on machine guarding of a pedestal grinder.
b. Physical security game: Physical security is the protection of personnel, hardware, software, networks and data from physical actions and events that could cause serious loss or damage to an enterprise, agency or institution. Physical security describes security measures that are designed to deny unauthorized access to facilities, equipment and resources and to protect personnel and property from damage or harm. Physical security involves the use of multiple layers of interdependent systems which include CCTV surveillance, security guards, protective barriers, locks, access control protocols, and many other techniques.

4.2. 3D modeling of safety game environment

The 3D virtual environment was created by using the Unreal game engine [23]. Unreal engine allows researchers and academic institutions to develop games and interactive virtual environments for educational purposes and redistribute them without licensing fees. In addition, Autodesk 3D Max software was used to create 3D models of the grinder, Personal Protection Equipment (PPE), and human operators [24].

In order to create the 3D virtual environment of the laboratory, it was also necessary to create models for surrounding mechanical equipment and PPE. First, photographs of a grinder as shown in Figure 1, and other mechanical equipment and personal protective equipment (PPE) were taken from different viewpoints for 3D modeling and texturing purposes. Second, these photos were brought into 3D modeling software to be used as reference images. Third, measurements (in inches) were taken for the equipment and then proper scale and unit data were input to the 3D modeling software. Finally, low-polygon modeling techniques were utilized to transform the real-world object to a virtual 3D model.

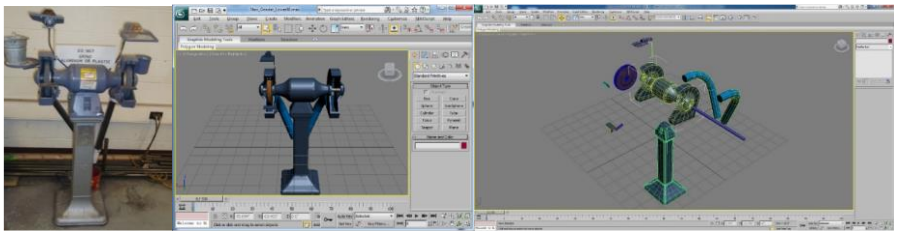


Figure 1. Picture of a pedestal grinder and completed 3D model

The 3D grinder model was unwrapped in UV texture coordinates to map the texture from photos. UV texture mapping is a process of assigning unique 2D coordinates for every 3D vertex in a polygonal model. This process was accomplished by using "UVW Unwrap" tool in 3D Studio Max to match the real photos. A similar approach has been used to convert other equipment, such as a fire extinguisher and a lathe, to be placed within the 3D virtual environment.

4.3. Creation of 3D virtual environment for safety game

The grinder model and other safety-related components were merged into the 3D virtual environment by utilizing Unreal Game Engine. This allowed students to interact and immerse themselves in a real-world-like environment without the risk associated with operating a grinder. In addition, necessary safety features could also be easily added within the virtual 3D environment.

To enhance student understanding of hazards associated with operation of a grinding wheel, the environment included 3D models of the PPE such as goggles, masks, ear plugs, 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 was also included to create a 3D virtual environment as close to a real laboratory environment as possible. The similar approach has been used to convert other equipment such as a fire extinguisher and a lathe to be placed within 3D virtual environment in Figure 2.

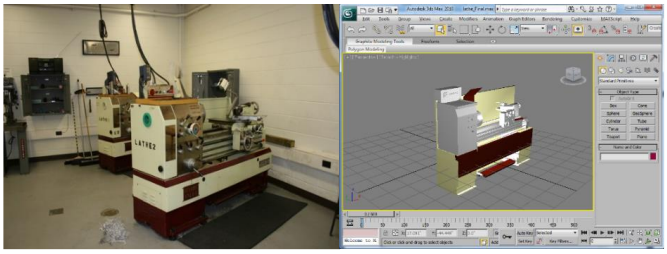


Figure 2. An example of visual conversion of a lathe

The virtual environment was created based on the layout of the mechanical engineering laboratory at Purdue University Northwest. Figure 3 show the virtual environment used in this virtual safety exercise.

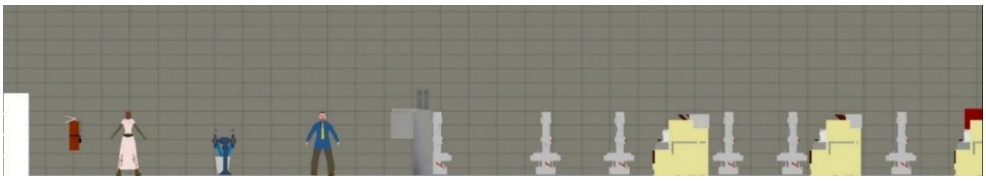


Figure 3. Front view of the layout

4.4. 3D Modeling for physical security game

Physical security game was developed in the Unity3D game engine (Unity 2019). This game can be classified as 3D Role-Playing-Games (RPG). The development of the 3D RPG physical security game consisted of three major technical components: (1) 3D character and game environment modeling, (2) animation of the 3D game characters, and (3) scripting/programming of the interaction between game characters and dynamic behaviors.

The physical security game environment was created by using the Unity game engine. In order to create the 3D virtual environment of the network operation center, it was also necessary to create models for physical building and data center interiors. Autodesk Maya software was used to create 3D models of the desktop computers, buildings, data and network servers, and furniture. The most important part in physical security game is to model the data center and data server. Figure 4 shows individual data server modeled in Autodesk Maya [25].

The 3D characters were created from Adobe Fuse software. Instead of modeling a 3D character from scratch, Adobe Fuse allows a user to assemble a 3D character from more than 20 base characters and further customize it with different weight, height, skin tones, and texture shown in Figure 5(a). The 3D character created in Adobe Fuse was transferred seamlessly into the Mixamo software shown in Figure 5(b). Mixamo offers hundreds of different motion clips that can be used in animation, so essential motion clips (such as idle, walk, run, talk, sit, and stand) were chosen for each character and exported to the Unity3D game engine.

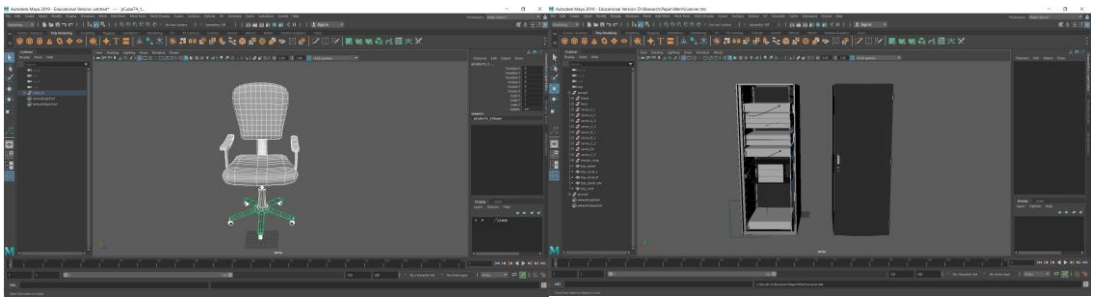
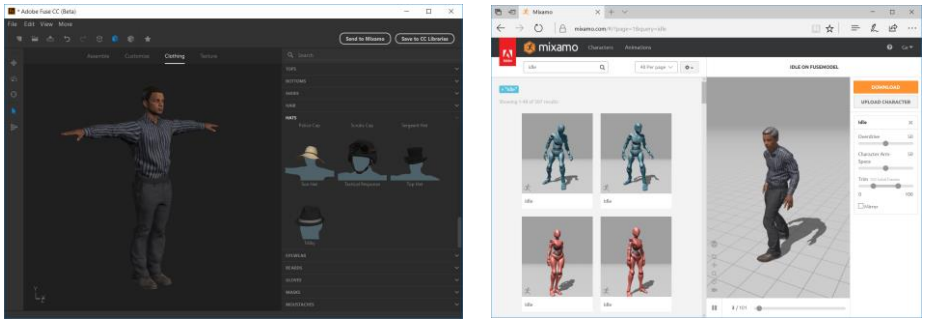


Figure 4. Examples of furniture and data server



(a) (b)

Figure 5. 3D character modeling and animation

The game environment was modeled mostly using Autodesk Maya software shown in Figure 6. Several 3D assets that related with physical security were imported from loyalty-free 3D assets from Unity Marketplaces. The behaviors of the 3D game characters were implemented by programming Unity C# script for each 3D character and dynamic assets in the game environment.

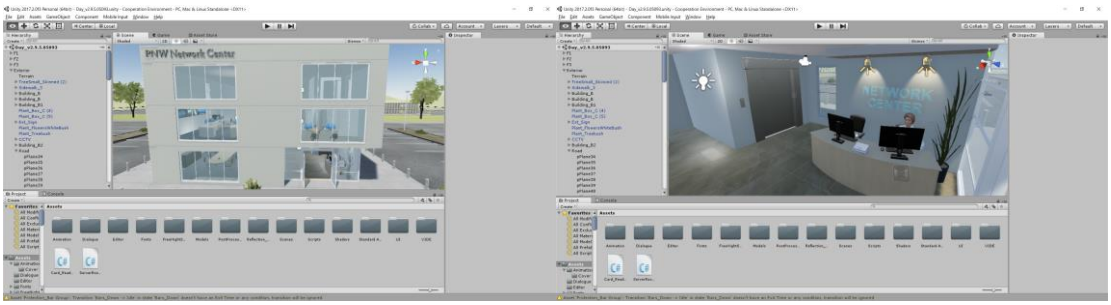


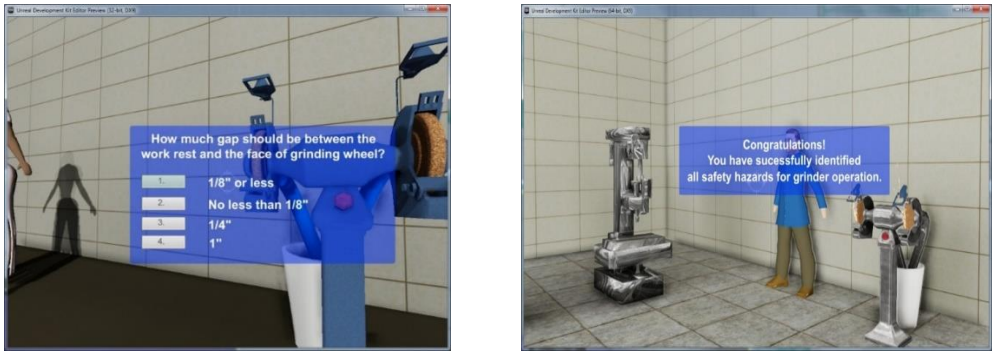
Figure 6. Simulated network center and building inertia modeling

4.5. Game programming for safety game

For safety game, three areas that affect safe operation of a grinder were identified. These are, 1) the safe distance between surface of a wheel and the work-rest, 2) the safe distance between surface of wheel and tongue guards, and 3) the proper placement of eye shield. To simulate potential hazards related to these three areas, the virtual grinder was broken into separate components so that each component could be operated independently. This process allowed each component to function separately and illustrate the possible hazards and allowed to be corrected in the virtual environment. Potential hazards and appropriate corrective measures were programmed into the virtual safety exercise that allowed students to visually identify and correct such hazards appropriately.

Once a trainee launches the virtual safety game, the user first must pick up the correct PPE and then must identify and correct hazards affecting an operator. For this safety game, a trainee moves a cursor over a specific hazard(s) and clicks a mouse on a computer screen. Once the trainee selects a pre-determined hazard within the virtual environment, an interface will pop up, allowing him/her to select an appropriate corrective action(s). The trainee's corrective action will then be compared with the preprogrammed action sequences inside the game engine.

If a student correctly selected PPE, identified all the safety hazards, and adjusted guarding components inside the virtual environment, immediate feedback will appear in Figure 7(b). Otherwise, trainees receive a failure notice that indicates they have not followed the correct procedures. However, trainees can retake the training until they correctly identify all the safety hazards in pedestal grinder operation. A typical user interface dialog for this safety game consists of descriptive texts, buttons, and dynamic text field that can be modified. The dynamic text field is updated based on the student's performance during the exercise. The user interface dialog is activated by clicking the mouse on a controllable mechanical part such as a tongue guard displayed inside the virtual environment in Figure 7(a). Unreal Kismet is a visual scripting language used to create the virtual safety exercise.



(a) (b)

Figure 7. Example of user interaction inside virtual environment

4.6. Game programming for physical security game

The purpose of physical security game is to teach the importance of physical security for network and data centers, and security measures using multiple layers of interdependent systems. For physical security game, several areas that affect physical security were identified. These are, 1) security guard at entrance, 2) CCTV surveillance, 3) protective barriers, 4) access control protocols, 5) password protection, and 6) doors and locks for protected areas.

Once a student launches the physical security game, user can either "walk" or "drive" into the security gate. When student drive close to the security gate, a message will pop up and show protocols need to follow to enter the facility. The student must provide his/her name and ID to go into the network center. After park the car, a student can walk into the data center building. Inside the data center, the student must register at the information desk to get visitor's pass to access any restricted area, as illustrated in Figure 8. The student need provide name and date of visit to get the pass.

Figure 8. Visitor pass registration and access restricted areas with pass

The student can use the visitor's pass to open the doors with access control on the first floor. After accessing all rooms in the first floor, take the elevator to the second floor. On the second floor, the student need to talk with the information desk to get the passwords for the server room and network monitor room. At each room student needs to provide correct password to open the door. After completing all physical security tasks, the student who completed in the shortest amount of time will be the winner.

The physical security game required 3D characters to walk, talk, and make unique gestures. To animate a game character in RPG style games, an animation component was added to the imported 3D character asset, providing these essential movements to the character so that a game player can control and animate the 3D virtual character in different situations. To make the virtual game character perform different actions based on the input event, a "Box Collider" from Unity Inspector control panel was added to the character to trigger different animations when another character entered the "Box Collider" area. A character control C# script was also programmed to allow a 3D character behave differently based on the input event used. Figure 9 shows a simple dialogue script that has been applied to a game character. The character will repeat "idle" motion until a game player approaches a non-player character. If a game player entered the "Box Collider" region, the character will start to talk with the game player by triggering a "talking" animation clip. A simple dialogue script was added to the 3D game character through the Unity Inspector control panel.

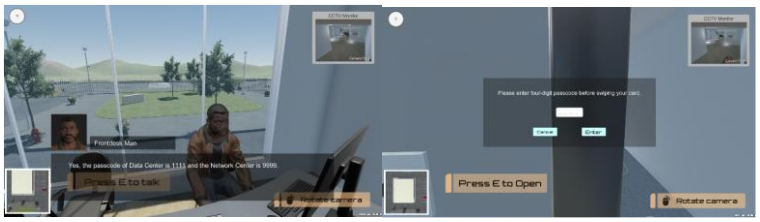


Figure 9. Passcode acquisition from the information desk and access restricted areas with passcode

5. ASSESSMENT

5.1. Assessment of grinder safety operation

The authors conducted a pilot study to determine the effectiveness of 3D safety game in three sections of the Safety and Health for Engineering Technologies course. This game was introduced in this course to enhance their comprehension of various safety topics. The effectiveness of this game was assessed by evaluating students' ability to recognize certain hazards related to the operation of a grinder. Students in each section received the same information on safe operating procedures of a grinder that included areas of potential hazards and appropriate measures to avoid these hazards. The following are the three sections: lecture only; lecture with laboratory exercise in the mechanical laboratory, and lecture with 3D safety game. Students in each section were assessed on knowledge gained about safe grinder operations. Student learning assessment were conducted for students in each section, a week after they had completed the lecture (section 1), lecture and physical laboratory exercise (section 2), and lecture and 3D safety game (section 3), respectively. On average, the first section scored 59%, the second section scored 76%, and the third section using virtual safety exercise received the highest assessment score of 82%. Thus the study supported the advantages of utilization of virtual safety exercise in enhancing students' learning.

5.2. Assessment of physical security game

The physical security game was introduced to high school students during one-week high school summer camp. Purdue University Northwest offered one-week summer camps from 2016 to 2018 to a total of 181 high school students with 107 underrepresented minority populations. During this one-week summer camp, each participant played this 3D physical security game at his/her own pace to learn the concept of security measures. Upon completion of camp, a survey was conducted to assess the student's satisfaction with 3D physical security game. A 5-point Likert scale was used to measure the students' satisfaction with game experiences ranging from 5 (strongly agree) to 1 (strongly disagree). Survey participants showed that game-based learning for physical security enhanced their knowledge in general security awareness. 86% of participants indicated that they knew more about physical security than they did before this camp. 82% of participants mentioned that they were more comfortable learning security concepts after playing the physical security game. 84% of participants responded that the physical security game was interesting.

6. CONCLUSION

This paper presented an innovative game-based learning method for safety and security education. Game based learning is an upcoming method to teach various topics in an educational setting. This method is especially valuable when learning safety and security concepts without the risk of getting physically injured. This article described the process of developing 3D safety and security games to assist student's learning. This process consists of four major steps: topic identification, 3D environment modeling, game programming, and assessment of learning. Based on the result of assessments, the 3D safety game produced similar learning outcome as physical environment. The physical security game was an excellent approach to assist high school students' learning of security concepts. This approach is beneficial to the future workforce as it exposes more high school students to the security discipline. This was also supported by the survey conducted after the summer camp, with average ratings of 4.26 out of 5 on all Likert-scale. The result of this study supports the potential of game based learning method to be utilized to various disciplines to enhance learning without putting learners in harm's way and get more realistic experience.

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