Learning by Playing: Serious Games for Safety Education

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Abstract

Many accidents occur during construction and maintenance of facilities. Both research and practice have established that choices made during the design and planning phases can affect worker safety. The prevention through design (PtD) concept is the consideration of construction site safety into the design of a project. Unfortunately, fresh engineering and design graduates do not possess the knowledge of construction worker safety and construction methods essential to successfully eliminate construction hazards through design. In most curricula, there is no room for an entire course focused on PtD. So, there is an opportunity to teach PtD to students using simulation games, as digital games are routinely considered as the most important and influential medium by college students. This research measures the effectiveness of the serious game developed to teach PtD to undergraduate construction engineering and management students. The results show that the game was more effective as compared to the traditional teaching method of lecturing.

INTRODUCTION

The construction industry employs 4.5 percent of the entire nonfarm workforce (BLS, 2017) and has 19 percent of the fatalities (BLS, 2016). These statistics indicate the seriousness of the safety problem in the construction industry. Over the past decades, concerns about the consequences of poor safety have increased, resulting in a decline in the incidence rate of fatal and disabling injuries. Despite all the development in safety science and engineering, construction is prominent for its poor safety performance. Mostly, the efforts to address safety concerns have been focused mainly on the construction phase, while the safety consideration in the pre-construction phase of a project is often overlooked. Consistently researchers find a strong link between workplace fatalities and the absence of a safety consideration in designs. Hence it is vital to identify potential risks and develop solutions to prevent work-related injuries, illnesses, and fatalities through design—this approach is called prevention through design (PtD) (Manuele, 2008).

In one research study, more than 200 fatal accident investigation reports were reviewed, and the results showed that 42 percent of the fatalities examined were connected to the absence of the safety in design approach (Behm, 2005). The underlying reasons for unsafe designs are the absence formal safety training of new engineering and design graduates, inadequate learning resources, and a shortage of the trained faculty to teach the prevention through design topics (Popov et al., 2013; Toole, 2005). The situation in construction management programs is somewhat better than engineering and design programs. Nearly all construction management programs teach construction safety, but there is no uniformity or consistency in the course syllabi, textbooks, or reference materials used in the various institutions in the United States (Z. Din, Rahman, & Gibson, 2017). Also, these construction programs focus on teaching a passive
approach of safety management during construction rather than the active approach of prevention through design. Hence a practical approach is to improve the safety environment is training engineers, construction managers, and designers to address safety hazards in design and pre-construction.

However, in most curricula, there is no room for an entire course focused on PtD. Therefore, several efforts are underway to find alternative ways to teach PtD. Under the NIOSH’s PtD initiative, textbooks' updates to provide PtD content and PtD teaching modules' development are being encouraged. One researcher implemented a 70-minute-long lecture-based intervention in the project management class of the civil engineering discipline, but this approach did not prove effective (Behm, Culvenor, & Dixon, 2014). Similarly, updating all the textbooks for every engineering program may take a significant amount of time and resources.

Hence, there is an opportunity to teach PtD to students using simulation games, as digital games are routinely considered as the most important and influential medium by college students. In digital game-based training systems, serious games are a predominant application type. Serious games are video games that allow the player to learn content in game-like environments (Michael & Chen, 2006). In particular, today’s “millennial” college students enjoy playing video games more so than past generations (Prensky, 2003), and this is evident from the increasing popularity of gaming over the past quarter-century. Therefore, by incorporating characteristics of games with the instructional material of PtD, the potential for motivating students to learn the new concepts in less time may increase. Students may also improve retention of knowledge through experiential learning using the game environment.

In this study, the researchers will explore how the prevention through design education of construction engineering and management students can be delivered effectively through the implementation of serious game activity. The study will also try to understand the relationship, if any, between variables (gender, relevant work experience, engagement, computers use frequency, and game-play frequency) and student test performance among different instructional techniques such as serious game, paper-based game, and lecture-based teaching. This work is part of dissertation research presented in partial fulfillment of the requirements for the Ph.D. degree in Civil, Environmental and Sustainable Engineering at Arizona State University (Zia Din, 2017).

**RESEARCH METHODOLOGY**

The research methodology selected for this research is quasi-experimental design. In educational interventions, the random assignment of participants to experimental (a game playing group for this study) or control groups (non-gamer in this study) is not always possible. Therefore, a quasi-experimental design would have to be used (Field & Hole, 2003). The intervention evaluation studies have used a pretest and posttest approach. The analysis techniques for the data collected are descriptive statistical analysis and inferential statistical analysis.

To find the effectiveness of different teaching methods, an in-class lecture, a paper-based game, and a serious game were developed and implemented to teach Prevention through Design to undergraduate construction engineering and management students. These pedagogies were used to study the impact of a teaching approach on learning performance. A total number of 118 students
from three classes at Arizona State University took part in the research study. Out of 118 students, 88 participants finished all the required phases of the data collection.

The proposed game “SafeDesign” was a computer-based application asked students to identify hazards and suggest solutions for a given scenario. The scenarios for the paper-based games and serious game were developed based on the PtD research carried out by Jimme Hinze and colleagues who provided a checklist to ensure safety consideration in the design, redesign and pre-construction processes (Gambatese, Hinze, & Haas, 1997). The lecture contents were adapted from NIOSH’s educational modules for teaching the PtD concepts (CDC, 2013).

The authors developed the game for this research and documented the process of the game development, which can serve as a guideline for other teachers and learners interested in the game development for their classes (Zia Din & Gibson Jr., 2018). Students were tasked with identifying hazards, such as falls, electrocution, and structural design-related hazards. A typical scenario is shown in Figure 1. After identifying hazards, students were asked to rectify the hazardous situation. The developed prototype allowed students to perform the following functions: to explore several scenarios such as working at the height or in a confined space; to visualize the design hazards that were present in the given scenario; to eliminate hazards and receive feedback about their hazard identification and elimination. A typical feedback screenshot is shown in Figure 2. With the incorporation of feedback in the game interface, users were challenged to think critically, to identify hazards correctly and to determine how to modify a particular design to improve safety. To complete this hazard identification and elimination activity, students were required to utilize higher-level thinking skills, beyond simple knowledge-based understanding. To suggest corrective measures, students needed to understand safety based on common sense.

![Figure 1 — A Typical Scenario of the Safedesign Game](image)

Based on the educational pedagogical research theory students were divided among three groups. One group was only delivered a lecture; the second group was given instructions and the SafeDesign game to play, and the third group was given a paper-based game. The data collected through the different treatment activities were compared to assess specific aspects of the learning
that varied based upon the format of the activity. This process of implementing the serious game, paper-based games, and lecture-based versions of the Prevention through Design activity as well as the analysis of results helped to answer specific research questions.

![Figure 2 – A Typical Safedesign Game Scenario Providing Feedback](image)

Learning score from three pedagogies was identified as the main effect to be studied during this research. The pedagogical approaches were considered as independent variables. While gender, game-playing frequency, relevant work experience, and computer use frequency was considered as confounding independent variables and covariates. Learning score was measured as the difference between the posttest score and the pretest score and was considered as the dependent variable.

**RESULTS**

The results showed that the SafeDesign game had a positive impact on learning; similarly, in-class lecture intervention also has the positive effect on learning. However, the overall performance of the serious game group was higher than the other intervention groups as shown in Figure 3. The paper-based game intervention did not work, and the students who used it earned the lowest score. The possible reason for better performance within the lecture intervention group was that the lecture was delivered during the class of a construction safety course. The students in the class were already familiar with terminologies and concepts of safe construction; this probably helped them to understand the prevention through design lecture, and this might have benefited them in the tests. The paper-based game and the serious game groups were truly comparable because the students in those groups had not taken any safety course previously. In those two groups, the students in the serious game group performed better on their post-test results. In order to determine whether gender, the learning game-playing experience, computer use, and the relevant work experience contributed to any of the pedagogical interventions, individual factorial design analysis was carried out to identify the main effects and the interaction effects of these
covariates. It was found that none of the factors had a statically significant impact on learning. Factors such as gender, the learning game playing experience, previous computer use experience and the relevant work experience did have a positive impact on the serious game performance, but the effect was not statistically significant. Figure 3 presents the ranges of average gain scores achieved by the participants in the three pedagogies. The box plot shows that the students in the paper-based game intervention performed differently as compared to the other two interventions. The paper-based game results contain four mild outliers marked by a circle (o).

**CONCLUSIONS**

Well-designed serious games have the potential to turn learning into a challenge through the right blend of instructive and entertaining elements. Furthermore, lecture-based teaching and learning can also help a student when teaching is based on the adult education principles of relevance, meet student’s needs, interactive education and connecting student’s background knowledge and experience. Among the various factors studied, no one proved to be an essential element of the study, which positively augmenting learning. For example, gender, previous knowledge, previous work experience and game playing experience did not seem to help toward learning for this relatively small sample. The illustrations on the paper-based game distracted students from the educational feature of the game in this study. Also, more work needs to be done concerning whether the SafeDesign game will have a positive effect to retain that knowledge in the long-term. Furthermore, future studies may be able to explore what features of a serious game are necessary for a positive impact on learning such as, improved visuals, audio, and 3D navigation functions. We should never consider serious games as a “magic wand” to improve learning performance, but serious games have the potential to be a great instrument for effective learning.
REFERENCES


