

Teaching Prevention through Design (PtD) Principles Using a Non-Traditional Pedagogical  
Strategy

By

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## ABSTRACT

Many accidents occur during construction and maintenance of facilities. Both research and practice have indicated that decisions made during the design and planning phases before work at a construction site can influence workers' safety (Behm, 2005). The Prevention through Design (PtD) concept is the consideration of construction site safety in the design of a project (Fred A Manuele, 2008). In one research study, more than 200 fatality investigation reports were reviewed, and the results showed that 42 percent of fatalities reviewed were linked to the absence of the PtD consideration in the design (Behm, 2005). This work indicates that the associated risk that contributed to the fatal injuries would have been reduced or eliminated if PtD had been utilized.

Researchers have identified the reasons for not applying the PtD concept in the design. The predominant reason is that most architects and design engineers do not learn about construction safety and construction processes required to eliminate construction safety hazards through design. Therefore, prevention through design education of architects, design engineers, and construction managers is critical to enable them to implement PtD. However, in most curricula, there is no room for an entire course focused on PtD. Therefore, one researcher delivered 70 minutes long lecture-based intervention in a project management class of the civil engineering discipline, but it did not prove effective (Behm, Culvenor, & Dixon, 2014). There is an opportunity to teach PtD to students using alternative teaching strategies such as computer games. Computer games are routinely considered as the most important and influential medium by college students. In this research study, a serious game and a paper-based game (the paper version of the serious game) were developed and implemented. The aim of the study was

to measure the effectiveness of alternative teaching methods to train students for safe design thinking. The result shows that the computer game engaged the students in comprehensive hazard recognition challenges. The learning experience of the students was compared to two other interventions: paper-based game and lecture-based teaching. The in-class lecture and the computer game were effective in delivering the prevention through design topics. The serious game was more effective compared to the lecture, and the paper-based game failed to motivate the students to learn. This dissertation discusses the possible reasons for success and failures of these pedagogical approaches.

## DEDICATION

This dissertation is dedicated to my father, Qamar-Ud-Din (late) and mother, Hajira (late) for whom I am eternally thankful. They were my best friends, my inspiration, and my source of love, support, and encouragement.

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## CHAPTER 1: INTRODUCTION

The construction industry employs 4.5 percent of the entire non-farm workforce (BLS, 2017) and has 19 percent of the fatalities (BLS, 2016). Over the past decades, concerns about safety have intensified into more focus, which has resulted in a decrease in the incident rate of fatal and disabling injuries. With all the progress in safety science, still, construction is prominent for its poor safety record. Often the efforts to improve safety largely focus on the construction phase of a project and consideration of safety in the design of a project is typically overlooked. Researchers have recognized a strong link between workplace fatalities and the absence of safe designs. This fact has continued to attract the attention of academics and safety professionals. For example, in one research project, more than 200 fatality details were studied, and the results showed that 42 percent of fatalities appraised were linked to the absence of safety consideration in the design (Behm, 2005). For this reason, 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) (Fred A Manuele, 2008).

To address worker safety in the design and pre-construction planning, several organizations have developed consensus standards such as ANSI/AIHA, Occupational Health and Safety Management Systems, and ANSI/ASEE, Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes (ANSI/AIHA, 2005; ANSI/ASSE, 2011). Realizing the importance of finding and designing out hazards in various products such as tools, equipment, processes, and buildings, NIOSH partnered with several professional organizations, including the American Society of Safety

Engineers, the Center for Construction Research and Training (CPWR), and others to launch the National Prevention through Design (PtD) Initiative in 2007 (NIOSH, 2014). The purpose of the initiative is to facilitate the creation and distribution of business tools, case studies, model projects, and best practices focused on design solutions that decrease worker health and safety issues and associated costs. Still, a major obstacle in developing safe designs is that most architects and design engineers are not knowledgeable in safety and construction processes fundamental to “design out” hazards (Gangolells, Casals, Forcada, Roca, & Fuertes, 2010). Typically, designers and construction managers learn about prevention through design once they enter professional practice because they are not exposed to the PtD concepts during their undergraduate education. Ideally, the engineers who are involved in designing portions of the permanent or temporary structures should possess the knowledge of construction safety to develop safe designs. Moreover, it is also important that those who hold the supervisory role as project engineers, superintendents, and project managers comprehend the concept of safety management during the design and pre-construction planning stage of a project.

To date, most of the university construction programs do not teach PtD along with more traditional safety content, and this content is usually limited to teaching OSHA 29 CFR 1926 (J. A. Gambatese, 2003). Unfortunately, in civil engineering curricula, there is no dedicated safety course. In one study, it was found that engineering curricula are already full with courses, and have no room for an entirely new course focused on Prevention through Design (Mann, 2008). Hence, one suggestion was to introduce PtD as a topic in existing courses. At one university, a 70-minute long lecture was delivered to undergraduate engineering students in a project management class, but the lecture-based

pedagogy did not prove effective (Behm et al., 2014). Hence, there is a need to consider innovative solutions to teaching and learning PtD without making major changes to the existing engineering and construction curricula. The goal of PtD education can perhaps be achieved through adopting a new pedagogy such as “the use of serious games.” The idea of serious games has been explained as a combination of entertainment and education in computer games. Opposed to normal (entertainment) games, serious games have a purpose beyond entertainment, for example, education, training, advertising and social change (Sørensen & Meyer, 2007; Winn, 2008). Serious games have gained the attention of academicians and been implemented in the following areas to improve students’ learning: Mathematics (Habgood, 2007; Ke, 2006), Languages (Johnson & Wu, 2008; Y. A. Rankin, Gold, & Gooch, 2006), Technologies (Sheng et al., 2007), Science (Dede, Clarke, Ketelhut, Nelson, & Bowman, 2005; Squire, Barnett, Grant, & Higginbotham, 2004), Health and Wellbeing (Beale, Kato, Marin-Bowling, Guthrie, & Cole, 2007; Lennon, 2006), and Social Studies (Paul, Hollis, & Messina, 2006; Piper, O’Brien, Morris, & Winograd, 2006). It is commonly recognized that serious games are very motivating and engaging settings and symbolize a new form of popular culture. In addition, there is a growing appreciation of the potential benefits of using serious games for teaching and learning (T. M. Connolly, Stansfield, & Hainey, 2007). This is why the author proposes a serious game to instill safe design thinking among construction management and construction engineering students.

### **1.1. Statement of the Problem**

The challenges of teaching the prevention through design concepts to future designers, engineers, and construction managers have not been fully met due to several

reasons such as the lack of room in the existing curricula for an additional course and reliance on traditional teaching and learning strategies (Behm et al., 2014). The development of traditional teaching resources such as textbooks and educational modules are being encouraged under the NIOSH PtD initiative; however, teaching and learning potential of innovative teaching strategies such as digital game-based learning should not be overlooked. Mostly serious games are the predominant application type of digital game-based training systems. In particular, today's "millennial" college students enjoy playing video games more so than past generations, and this is evident in 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 retainage of knowledge through experiential learning in the game environment. These improvements need to be assessed.

Many of the serious game evaluation methods described in literature are generally incapable of finding whether the player has learned anything from the game or whether serious games support learning in other ways; such as self-paced learning outside the formal classroom settings (Mayer et al., 2014). In the absence of convincing empirical proof supporting the implementation of games for learning and teaching of a particular subject, serious games can always be rejected as an exaggeratedly optimistic pathway. Often serious games are applied in different disciplines, but the effective empirical evaluation process is not always followed to compare serious games to traditional and alternative teaching and learning strategies. This indicates a lack of general assessment frameworks for serious games, particularly when implemented as a pedagogical strategy

(T. Connolly, Stansfield, & Hainey, 2009; de Freitas & Oliver, 2006).

In summary, there are three identified research problems:

- 1) Traditional teaching approaches are not sufficient to instill PtD concepts in students.
- 2) The general lack of empirical evidence to support the use of serious games for learning and teaching the PtD concepts.
- 3) The lack of specific frameworks for developing and evaluating serious games.

These research problems will be addressed in this study when a serious game will be implemented to teach the PtD concepts at the tertiary education level; the effectiveness of the serious game will be established through comparison with traditional and alternative approaches. The main contribution of this study to the body of knowledge will be the finding of empirical evidence for the use of serious games in the field of prevention through design education. This empirical evidence will be on desires for playing digital games in particular contexts and using serious games in a particular context to assess whether the approach can address some shortcomings of traditional and alternative approaches. To obtain the empirical evidence, an evaluation framework will be developed to measure the effectiveness of the SafeDesign game, a prototype serious game prepared for this study. The identified three research issues are not detached or separate and have been framed to provide a systematic approach to addressing the main contribution to knowledge.

The study will also try to understand the relationship, if any, between variables (gender, relevant work experience, computer use frequency, and learning game-playing experience) and student test performance among each of the instructional techniques.

Researchers have been investigating the effects of variables such as gender (Boyle & Connolly, 2008; Prensky, 2001a), learning game playing experience (Lennon, 2006), relevant experience (Russell, 2016), and computer use frequency.

The broader goal of this study is to highlight the value of using serious games in a particular subject to measure whether the approach can improve some inadequacies of traditional and alternative approaches.

## **1.2. Research Questions**

To address the identified research problems and scope, the following main questions and sub-questions have been formulated.

- 1) What is the pedagogical value of using a serious game to improve prevention through design education of construction management and construction engineering students?
- 2) What is the relationship, if any, between variables (gender, relevant work experience, computer use frequency, and learning game-playing experience) and student test performance among each of the instructional techniques?
- 3) What are the key design steps for creating a functional serious game to teach the prevention through design concepts to construction management and construction engineering students?

To answer the first two research questions, several hypotheses will be developed. For the third question, a detailed game development process and lesson learned will be documented.

### **1.3. Research Hypotheses**

This study will collect quantitative information on the effectiveness of three pedagogical interventions, namely the lecture, paper-based game, and serious game. Also, this research will collect qualitative information on variables such as gender, relevant work experience, computer use frequency, and learning game-playing experience. Utilizing all of this information, the following hypotheses will be investigated:

Hypothesis 1: An in-class lecture will positively impact learning.

Hypothesis 2: A paper-based game will positively impact learning.

Hypothesis 3: A serious game will positively impact learning.

Hypothesis 4: Gender will make an impact on learning.

Hypothesis 5: Previous knowledge and relevant work experience will positively impact learning.

Hypothesis 6: Computer use frequency and learning game playing experience will positively impact learning.

### **1.4. Research scope**

This dissertation focuses on developing and implementing a lecture, a paper version of the game and a 3D serious game to understand the benefits and challenges associated with creating and using these methods for educating students about the prevention through design concepts. The game prototype created, called SafeDesign, has been developed as a proof-of-concept level prototype. Although it is a functional tool, it still has certain limitations, and it is not intended to be a commercially viable system. It has served to illustrate several key educational benefits that a serious game can offer to

construction engineering and construction management students in the field of construction safety education.

The process by which SafeDesign game was developed is intended to help future researchers, but it has not been validated through the creation of several different versions of the game. The process documented is not considered the best possible process for development, but rather a process that, if followed, can successfully lead to a functional educational tool. The value of this work is in its contribution to the current body of knowledge on assessing the pedagogical value of serious game applications in construction safety education. This contribution can offer benefit to future research that intends to develop the application of serious games to enrich the construction education settings in general and construction worker safety education in particular. The rest of this dissertation focuses on this scope.

### **1.5. Dissertation outline**

Besides this introductory chapter, this research dissertation is organized into the following chapters and includes a set of appendices comprising of all the data collection instruments. In this chapter, the statement of the problem and the research questions those will be answered in this dissertation are introduced. Chapter Two provides a review of published work in the field of prevention through design and innovative pedagogies. Chapter Three outlines the research methodology and research tools used to collect data. Chapter Four provides a summary of lessons learned from the game development process. Chapter Five presents the results from the implementation of three pedagogical interventions. Finally, Chapter Six provides conclusions of the study.



## CHAPTER 2: LITERATURE REVIEW

To complete this work, a review of existing literature related to the topics in this research has been conducted. The survey of literature highlighted the key issue of implementation of prevention through design, construction safety, and safety education. It also reviewed educational strategies that have been suggested to offer benefits in a variety of contexts. The literature review helped to illustrate the current knowledge gap in understanding the effectiveness of non-traditional pedagogical strategies to develop safe design thinking among construction management and construction engineering students.

### **2.1. Prevention through Design**

Rinehart, Heidel, Okun and Barsan (2009) emphasized that business leaders expect designers, construction professionals, and engineers to identify and control safety risks early in the design development, rather than making modifications once workers get injured. Hence, this process of hazard identification and development of solutions to control those hazards should be performed during the design and pre-construction of facility development. This approach is comparable to “green chemistry,” which required designers to consider preventing pollution and sustaining our resources during the design process of products and processes to create these products. For many decision makers, this preventive approach is a common sense requirement to save resources and get a competitive advantage in the business environment and see it as crucial for lean production or eliminate waste. Many businesses worldwide have started practicing prevention through design as a part of their management approach for eliminating the costs linked to workplace fatalities, injuries, and illnesses. (Rinehart et al., 2009).

One major obstacle to implement the PtD concept in businesses is the absence of training for newly graduating designers, engineers, and construction professionals on how they can add value to the industry by recognizing safety risks in the design and taking measured steps to mitigate them. In one study, several senior managers from Fortune 500 companies mentioned the absence of PtD knowledge in engineering and management education. They mentioned resources are devoted to training new engineers and managers to understand the basic concepts of prevention of health and safety hazards at the workplace. They also pointed out mistakes designers make resulting in the expensive need to redesign or rebuilt structures, facilities, and operations to control hazards that were not considered and controlled during the design and planning phase. Current business environment has a rising demand for designers, construction professionals, and engineers who are familiar with the PtD concepts (Rinehart et al., 2009). So that they can eliminate or reduce hazards in the early design process, and this approach is simply better than controlling hazards or protecting workers from hazards after construction work starts (F A Manuele, 1997).

This dissertation highlights the significance of including the prevention through design concepts in construction education. Teaching the PtD concepts do not entail full course. The concepts can be merged into existing classes by using innovative pedagogies. Instructors can include PtD messages in classes by including serious games, which can be played by students even outside the classroom.

The section below provides a historical perspective of prevention through design and its relation to construction and engineering education. It also provides a brief overview of the PtD National Initiative. This initiative lays out a comprehensive plan for

PtD promotion and PtD education and research are two essential components of the plan. Finally, several sub-topics of PtD are presented those could be used for developing scenarios to teach PtD.

## **2.2. PtD Considerations in Design and Pre-Construction Planning Process**

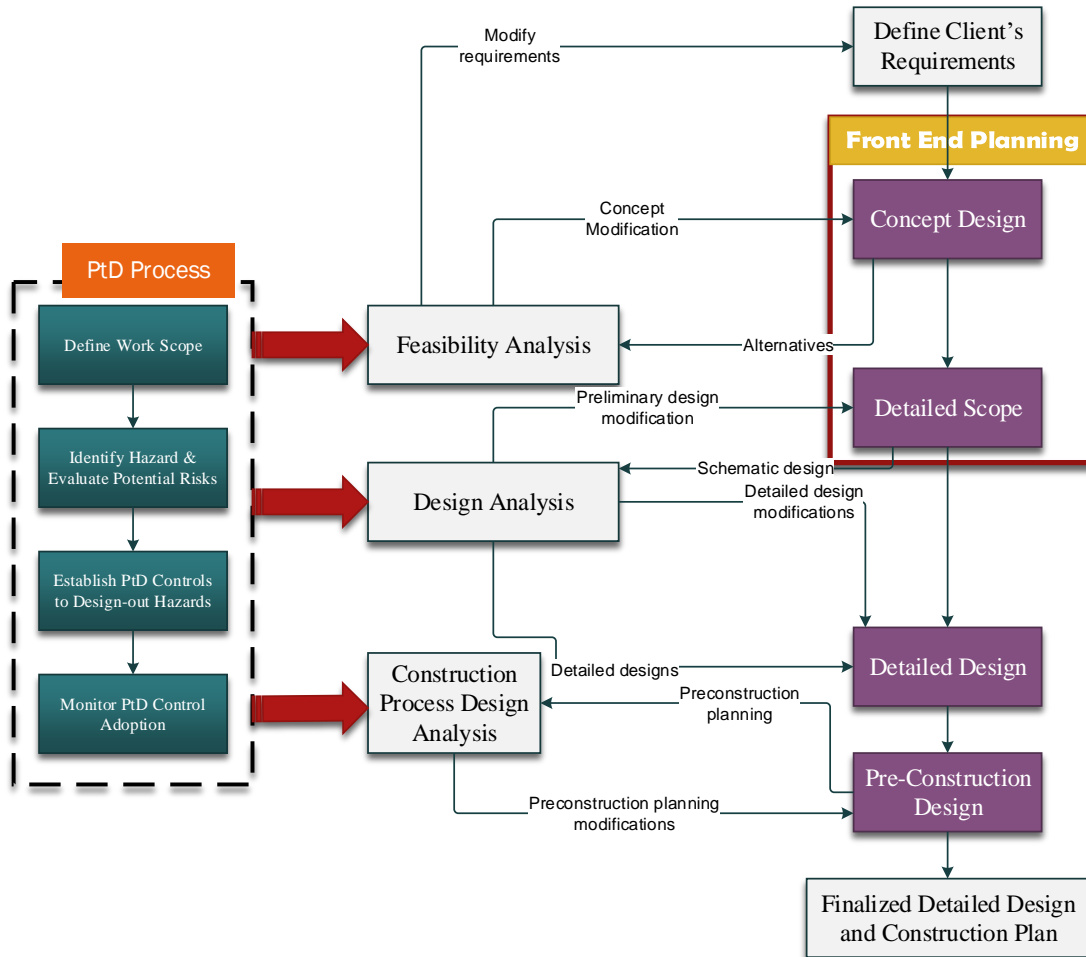
Worker safety is considered the responsibility of contractors under the traditional project delivery method, also called design-bid-build (Jimmie Hinze & Wiegand, 1992). However, in the last two decades, researchers have found that considering safety in the design and pre-construction planning well before the construction work starts is critical to protecting workers during the construction and maintenance of a facility. Kamardeen (2013) outlined an approach for implementing the concepts of prevention through design is shown in Figure 1. In order to make this method comprehensive, the researcher modified it by including the pre-construction planning process as part of the PtD implementation plan. The following section provides a brief introduction of the PtD implementation process.

### **2.2.1. Front End Planning Process**

The consideration of PtD in the design process starts with the front end planning process where concept phase is completed to evaluate project alternatives from health and safety perspective. Detailed scope phase is the next critical stage where health and safety concerns identified during the concept phase are assessed and preliminary design from health and safety perspective is analyzed.

After completing the front end planning process, the detailed design phase starts in which all health and safety hazards and their control are identified and implemented.

The earlier stages of design development are revisited to finalize health and safety analysis.



**Figure 1. PtD consideration in design and pre-construction planning process (Adapted from Kamerdeen 2013)**

### 2.2.2. Pre-construction Planning Process

During the pre-construction planning process, significant decisions regarding site layout, material and equipment storage, and design of temporary structures (trench protection works, scaffolding and formwork erection and removal) are made. In this study, scenarios related to the pre-construction design phase of this study were developed and tested. Most of the students participating in this study were in the construction

management program; therefore, the topics related to safety in the pre-construction planning process appeared to be a suitable choice.

### **2.3. Prevention through Design History**

The concept of PtD and its connections to design and construction are not new. Beginning in the 1800s, the demand for safer designs for motor engines, controls for elevators, and boilers became the standards, followed by safety requirements for other devices and processes created by engineers to protect workers. To highlight the role of engineers in the safe design development, in 1947, the Canons of Ethics for Engineers stated, also:

He will make provisions for safety of life and health of employees and of the public who may be affected by the work for which he is responsible (Engineers Council for Professional Development, 1947).

Similarly, Construction Management Association of America (CMAA) emphasizes that:

CMAA believes that worker safety and health, environmental protection, and protection of property and the public during construction operations not only safeguard the workers, environment, and public but contribute concretely to overall project success... (CMAA, 2015).

Since the late 1970s, the concepts of safety, such as of integral or inherent safety, safety by design, design for safety, safe design appeared, mainly in the chemical industry after major industrial accidents. Therefore, the chemical industry now greatly recognizes the value of safer designs (Rinehart et al., 2009). Similar, acceptability of safe design development is also desired for the construction industry.

In the 1980s, the National Institute for Occupational Safety and Health (NIOSH) initiated the Safety and Health Awareness for Preventive Engineering project to educate designers of the significance of health and safety related technical problem present in

engineering projects. To spread PtD education, nine teaching units were prepared and are available to the public free of cost, on the NIOSH website (CDC, 2013).

To develop suggestion for PtD implementation, a workshop was organized in 1996 and stakeholders from industry, government, and engineering educational institutions participated in addressing two fundamental issues: First, what occupational health and safety awareness an engineer should possess upon finishing a bachelor degree? Second, what are the best and practical ways to deliver this knowledge? One finding of the meeting was that engineering curricula have no room for entire courses on health and safety; therefore, these topics should be introduced through the existing course arrangement to teach relevant OSH concepts (Schulte, Rinehart, Okun, Geraci, & Heidel, 2008a).

There have been several articles on the lack of Occupational Health and Safety (OHS) education in undergraduate engineering education (Gesetzliche, 2011; Mann, Gambatese, & Mann III, 2008); and researchers have highlighted the need to develop methods to teach OSH to students by institutionalizing those methods into engineering programs (Rinehart et al., 2009).

There is a persistent effort in the USA to stress upon the need for health and safety education of new engineers and managers, so they should be able to apply PtD concepts after they graduate. This requirement also reflects in the first Fundamental Canon of the Code of Ethics for Engineers, which demands engineers should hold safety, health, and welfare of the public as their top priority (National Society of Professional Engineers, 2007).

The Accreditation Board for Engineering and Technology (ABET) has safety as

an accreditation criterion for the 2016-2017 Accreditation Cycle that demands engineers to develop:

Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (ABET, 2016).

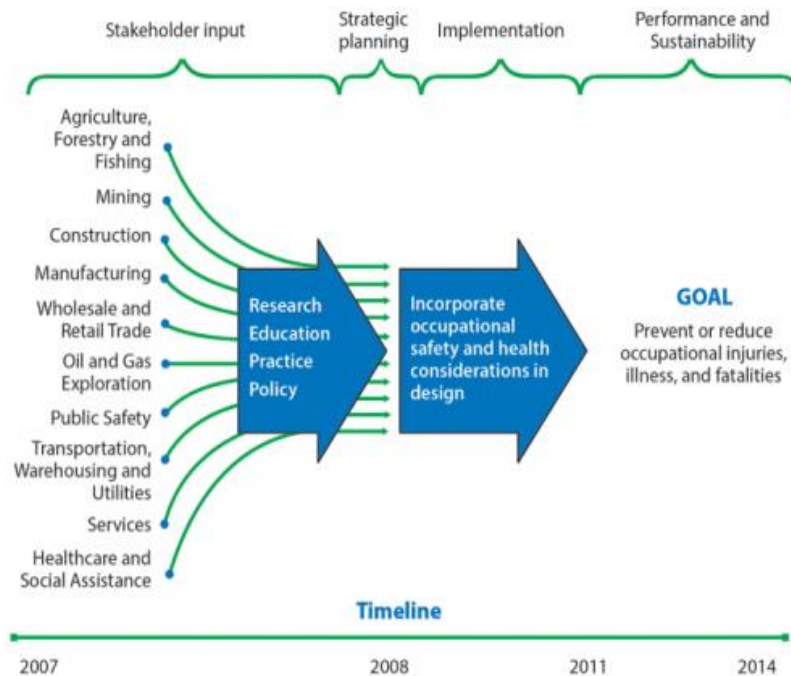
Keeping in view the impact of the decisions of engineers and construction managers on worker safety, the importance of learning how to identify and control safety and health hazards is evident. Moreover, industry leaders expect new engineers and designers to reduce costs related to unsafe designs. Besides the cost of retrofitting, neglecting safety in the design process can expose workers to hazardous chemicals, ergonomic hazards, explosions, fires, fall, amputations, etc.

#### **2.4. Prevention through Design National Initiative**

The significance of PtD is now being realized among all industry sectors and academia. Special issues of scholarly journals have been devoted to the subject, for example, the Journal of Safety Science's special issue in 2016 on Safe Design and a special issue of the Journal of Safety Research: Prevention through Design published in 2008. To support the adoption of the PtD concept in the industry, which is gaining its popularity in many of the main industries in the world, the National Institute for Occupational Safety and Health (NIOSH) initiated a collaborative initiative in 2007. The purpose of the initiative is to facilitate the development and distribution of design guidelines, best practices, and model projects focused on addressing worker health and safety issues and associated costs. The initiative outlines the PtD implementation in different industry sectors through four core areas: practice, policy, research, and education (NIOSH, 2011). Figure 2 shows the framework of the initiative delineating the

goals and timeline to achieve them. Update information on the Initiative is available on the NIOSH PtD website “<https://www.cdc.gov/niosh/programs/ptdesign/sector.html>.” In order to prepare future designers who are familiar with the PtD concepts, the Initiative stresses on “education,” and in one study, Mann et al., (2008) summarized recent activities and suggested future actions in the field of education to meet the initiative’s goals. To implement the initiative, a broad PtD National Strategic Plan has been developed based on the suggestions from all relevant disciplines and industries. Further information on the plan is available on the NIOSH PtD website.

## Prevention through Design National Initiative



**Figure 2. PtD strategic plan (NIOSH 2011)**

Researchers have documented several obstacles in the implementation of PtD and the following section summarize a list of those hurdles.



## **2.5. Impediments to Prevention through Design Implementation**

Despite the attention of the public and private organizations to encourage the application of prevention through design concepts in the design process, the lack of adoption of prevention through design solutions clearly indicates that there are other reasons behind health and safety business decisions (Biddle & Popov, 2014). In a study J. A. Gambatese, Behm, and Hinze (2005) summarized the following barriers that may affect designer's involvement in prevention through design implementation (J. A. Gambatese, 1998, 2003; Hecker, Gambatese, & Weinstein, 2004; J Hinze, 1992; Toole, 2004) such as: 1) virtually absence of guidelines from regulators for designers to consider safety of workers during the design process; 2) more focus on the employer's duty to protect workers; 3) designers' fear of underserved worker safety liability; 4) designers' lack of knowledge about prevention through design concepts; 5) limited prevention through design body of knowledge; 6) limited interaction during the design process between architects and engineers due to the traditional project delivery method; and 7) lack of general safety education of designers. Several efforts are underway to overcome these hurdles, and the current research is part of the efforts to educate designers and construction managers on prevention through design.

## **2.6. Need for Prevention through Design Education**

Construction is a high hazard industry and workers involved in the construction, renovation, and demolition of facilities suffer a disproportionate share of occupational fatalities and health issues. The rate fatalities in the construction industry is greater than the manufacturing industry. "Out of 4,836 worker fatalities, in private industry in the year of 2015, 937 or 19.4 percent were in construction, that is, one in five worker deaths last

year was in construction” (OSHA, 2016). The high fatality rate in construction calls for the measure beyond traditional safety management approaches. An important approach to improving construction safety involves the consideration of worker safety in the design of a project. There are two synonymous terms used for this approach “Design for Construction Safety (DFCS)” and “Prevention through Design (PtD).” The importance of PtD has been emphasized since 1992 when Jimmie Hinze highlighted the role of designers in construction worker safety (J Hinze, 1992) and later in 1997, Construction Industry Institute developed a set of suggestions for designer and project managers how to consider safety in design and redesign and these suggestions published under the title of “Tool to Design for Construction Worker Safety” (J Gambatese & Hinze, 1999; John a. Gambatese, Hinze, & Haas, 1997). These efforts and others led the National Institute for Occupational Safety and Health to launch “PtD National Initiative” in 2007, which calls for the paradigm shift through education, research, practice, and policy (Zarges & Giles, 2008). The initiative considers that academia is one of the major players to bring about change in the current culture of safety management.

## **2.7. Engineering and Construction Education at Large**

Students have diverse learning styles, methods, and inclinations in the ways they take in and process information (Claxton & Murrell, 1988). Some students incline to focus on details, data, and procedures; others are more comfortable with concepts and mathematical methods. Some overreact to visual information, such as pictures, drawings, and diagrams; others get more verbal forms, including written and spoken explanations. Some choose to learn through participation in the active and interactive learning environment, while others prefer to know more on their own. In our daily life,

information usually originates in visual and verbal forms together, and much of it will be absent to somebody who cannot process well in both of these forms (R. Felder, 1996; Hawk & Shah, 2007). To date, in many universities teaching approaches have commonly not drifted from lecture-based teaching methods that do not highlight visual learning and there is a disparity between teaching styles and learning styles of students in the discipline of construction and engineering (Mills & Treagust, 2003). This fact calls for the use of other options to teach students. For example, concentrating on a visual method to teach intricate theories could be helpful. Recent advances in video game technologies potentially offer an efficient and a visual learning environment, both for leisure and learning purposes. This type of active learning would help them to take and refresh their knowledge without spending much time at school.

## **2.8. Civil Engineering Education at Arizona State University**

There are significant challenges associated with the education of engineering students at colleges today. This research explores the potential for new educational methods to take a first step toward delivering the safety education of engineers and construction managers by focusing on construction engineering and management students at Arizona State University. Specifically, this work explores the topic of prevention through design in the discipline of construction engineering and construction management. NIOSH has launched the Prevention through Design Initiative, which describes that “one of the best ways to prevent and control occupational injuries, illnesses, and fatalities is to design out or minimize hazards and risks early in the design process”(Schulte, Rinehart, Okun, Geraci, & Heidel, 2008b). This approach to implementing the initiative consists of four focus areas: research, practice, education, and

policy (Schulte et al., 2008b). The goal of the initiative is that construction management and construction-engineering students should become better prepared to understand the design implications related worker health and safety and must try to eliminate risks of the project in the design development and pre-construction planning phases.

Civil engineering education at Arizona State University is offered in a variety of combinations, namely, general civil engineering, concentrations in environmental engineering and sustainable engineering. However, no dedicated course on health and safety is offered to civil engineering students. This situation leaves civil engineers unprepared to eliminate hazards during the design of a project. In striving to achieve the goals set forth by NIOSH, there is a need to teach the basic concepts of prevention through design early in the educational process (Rinehart et al., 2009).

## **2.9. Construction Management and Construction Engineering Education at Arizona State University**

In the Del E. Webb School of Construction at Arizona State University, undergraduate construction management and construction engineering students take a required Construction Safety course (CON/CNE 271). Topics covered in the course focus on OSHA Construction Industry Regulations (29 CFR 1926), which means the emphasis is on safety management during the construction phase of a project. After completing this course successfully, the students are awarded an OSHA 30-Hour training completion card.

Among faculty and students, the interest in construction health and safety is growing due to the commitment of the school's leadership. For example, several faculty members are researching the topic of construction health and safety. Furthermore, safety

professionals from different engineering and construction organizations come to share the industry's best practices during the two dedicated annual Safety Days at the Del E. Webb School of Construction. The Safety Days offer students an opportunity to interact with construction and safety professionals to get an idea of what challenges they face while working on a construction job site.

The author believes that this basic understanding of PtD in the first year of education adequately prepares students for their future academic years when they will be learning design and project planning. The use of innovative pedagogies such as serious games may motivate students to start learning the PtD concept inside and outside the classroom settings. In the next section, an overview of serious games will be presented.

## **2.10. Serious Games**

The education is in crisis because the traditional approach of education with one teacher lots of pupils is failing to motivate and train students (Svinicki, 1999). Also, online education, mostly limited to a set of online reading homework and a final test, is not delivering the knowledge necessary for effective education (Prensky, 2001a). Therefore, when educationists see the enthusiasm and long hours people spend playing challenging computer games, they imagine using this medium to teach educational content. Hence, the potential of serious games to motivate learners is a beacon of hope for educators (Van Eck, 2006).

Theories addressing the benefits of games in the classroom have emerged along with the rise in popularity of video games in contemporary culture. Prensky has repeatedly argued that the characteristics of younger generations indicate that students would thrive in learning environments that include serious games (Prensky, 2005). For

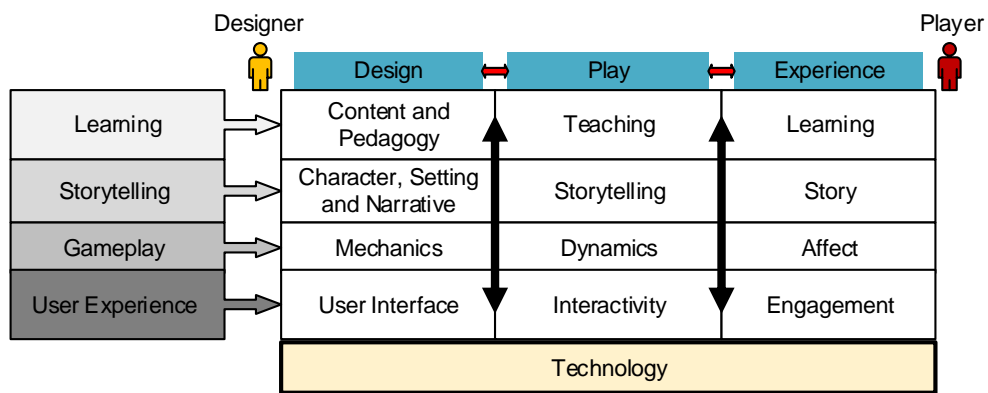
instance, research conducted by Squire (2004) suggested that students in a history class were more engaged in learning when using the game *Civilization III* with the traditional teaching method. Other findings from research about the use of serious games include increasing social interaction (Oliver & Carr, 2009), benefiting from experiential learning and constructivism (Dieleman & Huisingsh, 2006; Saunders, 1997; C. Wagner, 2008), and increasing cognitive learning achievement (Chuang & Wei-Fan, 2007).

In this research, the goal is to conduct an empirical investigation attempting to determine the effectiveness of serious games by comparing the differences in learning performance of students taught using either a serious game, traditional lecture, or a paper-based game. This effort will advance the research in the use of serious games in construction management and construction engineering education. Additionally, demographic information will be collected to determine whether differences exist in the test results of different types of students when using serious games. The ultimate goal of this research is to identify whether or not serious games should be considered effective instructional tools for PtD education. The following section provides an overview of the literature on frameworks for serious game development, which will provide a foundation for the design of the SafeDesign game.

### **2.11. Serious Game Development Framework**

A typical design for learning games is the intersection between learning theory, educational content, and game design. In order to develop serious games, academics are interested in the application of teaching and communication theories. The content experts provide subject matter, which is the prevention through design suggestions developed by CII in this case, and game designers like to develop an engaging and entertaining

gameplay (Winn & Heeter, 2007). Several researchers have suggested frameworks to develop games. LeBlanc (2005) proposed the mechanics, dynamics, and aesthetics (MDA) framework, which represents the relationship between the designer and the player. According to the MDA, the designer develops the mechanics or rules of the game. The player's feedback helps the designer to create the desired aesthetics through an iterative process. However, the MDA framework does not consider the core requirement of serious games, that is, learning theories. Therefore, the design, play, and experience (DPE) framework was developed to address this deficiency in the MDA framework. The DPE framework outlines a process to design a serious game for learning. The DPE framework presents the components of serious game design as layers, and these are the learning, storytelling, gameplay, user experience, and technology layers. Each layer is further divided into design, play, and experience aspects as shown in Figure 3. The bottom layer represents technology. Usually, the designer does not develop technology, but the design of game requires technology (Winn, 2008).



**Figure 3. Design, Play, and Experience (DPE) framework for serious game design**

(Winn, 2008)

### **2.11.1. Storytelling Layer**

In a game, storytelling has two aspects: from the designer's perspective and the player's perspective (Rouse, 2010). In the SafeDesign game, the designer's story is the storytelling about identifying hazards and taking measures to correct them, and that story will be designed into the game. The scenarios presenting different construction activities were used to set the stage, and various construction activities with hidden and obvious safety hazards in the game were presented in the game. The scenarios convey content by engaging learners.

As soon as the player engages in the game, the player's story takes place as a combination of designer's story and the choices the player makes while playing the game. Some game genre such as adventure and role-playing games require stronger designer stories, while others require no designer story, for example, classic Pacman and Tetris. The SafeDesign game has both the designer's story and the player's story. In this game, the player experiences gameplay challenges such as how to correct certain hazardous situations to develop a safe design. In this game, storytelling design is inspired by the learning outcomes.

### **2.11.2. Gameplay Layer**

The gameplay layer enables the player to interact with a game. Gameplay offers various challenges for the player and motivates the player to take action (Adams & Rollings, 2007). The gameplay layer is composed of three components: mechanics, dynamics, and effects. The game rules come under the component of mechanics that outline the process of the game world, such as the challenges the player will have, the actions the player will take to overcome those challenges, and the goal the player will



pursue to play. In the SafeDesign game, the player can interact with different elements in the scenario to identify various assets and select options from a given set of control measures. The dynamics are the outcome of the game rules when the player interacts. For instance, in the SafeDesign game, there will be a hazardous condition in a given scenario, and after the application of rules, that is, selecting an answer from a list of options, and then the selection of control measures, the player will achieve the goal. As a result, the options selected by the player can be correct or incorrect, and this result is dynamic. From a player's viewpoint, the SafeDesign game will be considered as entertaining or not entertaining. In order to provide reasons for fun experience, the researcher considered providing options such as rewarding after successfully identifying and controlling a hazard.

### **2.11.3. User Experience Layer**

From the perspective of the player, this is the most important layer. Because the player expects the game designer should focus on creating entertaining gameplay and make entertainment accessible (Saltzman, 2000). This layer consists of the user interface, and the goal of the user interface is to provide a place through which a user interacts such as selecting answers from a set of given choices. The game design displays itself through the user interface. The interface includes how the game is controlled, how information is presented to the player, and the game audio (the sounds and music). In other words, this includes anything not directly part of the gameplay. The SafeDesign interface will encompass everything the player sees, hears, and interacts with, such as different construction scenarios, the number of hazards identified, option buttons to switch between various activities and feedback display. The user-interface will show control

options for sound and gameplay, pause, and finish options.

#### **2.11.4. Technology Layer**

In digital game development, everything is grounded in technology. Some game design sets are more reliant on the technology than others. In the DPE framework, the user experience is tightly linked to technology. In order to design a game that is less dependent on technology, it is possible to design a paper-based game using the gameplay, storytelling, and learning components of a serious game and examples of such games are board or card games. Definitely, for such games the need for technology will be lesser than a computer-based game.

The paper-based approach will be used in this study too. The goal is to use the paper prototype to assess the effectiveness of the alternative pedagogy. The user interface of the paper-based game will be very different from a digital version of the same game. Therefore, the player will have a different experience while playing the paper-based game compared with playing the computer-based version. Moreover, there are restrictions on what game designs are possible without computer technology. For example, certain designs can only be implemented in computer technology such as game mechanics using a simulation of Newtonian physics or a user interface for displaying a 3-D world; these cannot be presented well in a paper-based game. These intricate game mechanics and user interface features are only possible with sophisticated technology and, consequently, will need to require superior means to implement (Winn, 2008). Therefore, technology can both empower and limit the game design. To develop the SafeDesign game, the technology of the Unity 3D game development engine was used. Unity is a game development engine prepared by Unity Technologies and used to

develop serious and entertainment games for PC, consoles, mobile devices, and websites.

#### **2.11.5. Influence between Layers**

It is evident from Figure 3 that all the layers in the framework impact each other in a serious game and learning performance is influenced by the quality of storytelling, gameplay, and user experience components of a game. Researchers consider that serious games help to improve learning when gameplay is based on the proposed learning outcome (Sherry & Pacheco, 2004).

#### **2.12. Learning Styles**

In order to understand how SafeDesign game can help students, it is important to know the learning styles of students. There are several classes for learning styles of students. Research has recognized and defined different learning styles among students, in general (R. M. Felder & Silverman, 1988). The findings of this research are summarized in Table 1. Construction engineering and construction management students probably have a strong preference toward active, visual learning experiences along with other learning preferences where they can obtain feedback about their experience.

In addition to the different learning styles that can be present among students, the actual process of learning has been broken down into components (Krathwohl, 2002). Researchers have examined Bloom's Taxonomy (Bloom, 1969) and updated several aspects of the learning process originally described. These specific processes can be seen in Table 2, along with a few common words to describe each cognitive process. These learning processes have been identified and modified by several different researchers (Bloom, 1969; Krathwohl, 2002; P C Wankat & Oreovicz, 2015). While all of these six cognitive processes listed in Table 2 can be taught to students, frequently only the first

three are tested (Phillip C Wankat & Oreovicz, 1992). This presents a learning and teaching opportunity to organize learning activities to inspire students to apply the higher level thinking skills that will be necessary for their academic and professional growth.

**Table 1. Preferred learning styles** (Adapted from R. M. Felder & Silverman, 1988)

Preferred Learning Style	Preferred Teaching Style	Description of Learning Style and Teaching Styles
Sensory Perception	Concrete Content	Learners prefer using senses to gather information. Teachers should use concrete facts, data, and experimentation.
Intuitive Perception	Abstract Content	Learners want to experience learning through imagination, and insights. Teachers can teach intuitors through principles and theories.
Visual Input	Visual Presentation	Learners prefer to see pictures and flow charts, time lines, and figures. Teachers should engage visual stimuli of learners.
Auditory Input	Verbal Presentation	Learners prefer to learn through hearing and talking. Teachers should engage learners in discussions.
Inductive Organization	Inductive Organization	Learners prefer to observe a situation first and understand the problem later. Teachers should use case studies to teach these learners.
Deductive Organization	Deductive Organization	Learners prefer to learn from basic principles for application to broader general concepts. Teachers should teach principles first and applications later.
Active Processing	Active Student Participation	Learners prefer to engage with experimentation to learn. Teachers should design activities to engage these students.
Reflective Processing	Reflective Student Participation	Learners prefer to listen and observe. Teachers should prepare an interesting material for such students.
Sequential Understanding	Sequential Perspective	Learners prefer to learn from the material presented in logically ordered progression. Teachers should prepare their lectures/materials based on logical flow.
Global Understanding	Global Perspective	Learners prefer interdisciplinary information. Teachers should prepare material with connections to other fields of knowledge.

Table 1 shows a summary of the preferred student learning styles and the corresponding preferred teaching style with a brief description of that style adapted from (Felder and Silverman 1988) and Table 2 presents a cognitive process for learning.

**Table 2. Description of the cognitive process** (Based on Krathwohl, 2002)

Cognitive Process	Description of the Process
1. Remember	Recognizing, Recalling
2. Understand	Interpreting, Exemplifying, Classifying, Inferring, Comparing, Explaining
3. Apply	Executing, Implementing
4. Analyze	Differentiating, Organizing, Attributing
5. Evaluate	Checking, Critiquing
6. Create	Generating, Planning, Producing

### **2.13. Educational Theories**

There is no one single best way to teach students different subject topics because of students' different learning styles. However, it is believed that digital games have the potential to be a valuable training tool because of their ability to provide the experience of interactive, engaging and immersive learning activities. Learning theories try to explain the usefulness of various learning settings and pedagogies, which have potential to offer value to students with diverse learning styles. In this section, the educational theories and literature that relate to the core education features present in SafeDesign game are presented.

#### **2.13.1. Behaviorism**

This theory states that learning occurs through receiving compensation for the right answer to the stimuli in a game and these games are termed as edutainment or serious games. For instance, in Math Blaster- a game for teaching Mathematics for boys

and girls, the player rewards come after shooting balloons if getting a sum correct (JumpStart Games, 2014). The right answer of the sum is also a reward itself.

### **2.13.2. Cognitivism**

Cognitivism considers the mind as a center to acquire knowledge through various modes such as text, pictures, and sounds. This allows a player to recognize and analyze problems and relate prior learning. Learning is the process of linking symbols in a meaningful and striking way. The player is engrossed in a world that allows them to use the brain to memorize, recall of stored information, and problem solve. Many serious games are designed generally based on this theory of learning.

### **2.13.3. Constructivist Learning**

Constructivist learning follows the theory of Constructivism that states “learners create, or construct, their own understanding, rather than having information imparted by an instructor, curriculum, or media” (M Kebritchi & Hirumi, 2008).

Some game designers use the experiential learning theory, where learning happens through experiencing activities, and this is based on Kolb’s learning cycles: concrete learning, abstract conceptualization, and active investigation.

### **2.13.4. Practice, Experience, and Interaction**

Experience-based learning can be woven into games. The situated learning concept is used for creating a game world where the players can experience the real world like environment. For example, serious games and simulators used by the military often based on this model. The sociocultural theory can be applied to develop games to learn discussion, reflection and analytical skill where players can interact with their

fellow players.

## **2.14. Summary**

In this study, the researcher will explore how the prevention through design education of construction engineering and management students can be improved through the implementation of the serious game.

Using results from the literature review, the proposed game will be a computer-based application that will allow students to explore several scenarios related to working at height or in confined space; visualize the design hazards that may present in a particular scenario; eliminate hazards, and receive feedback about their hazard identification and elimination. With the incorporation of feedback in the game interface, users will be 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 will be required to utilize higher-level thinking skills, beyond simple knowledge-based understanding. To suggest corrective measures, students will need to understand safety based on common sense.

Based on the pedagogical research theory students will be divided into three groups. One group will only be delivered a lecture; the second group will be given instructions and the SafeDesign game to play, and the third group will be given a paper-based game. The data collected through the different treatment activities will be compared to assess specific aspects of the learning that varied based on 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

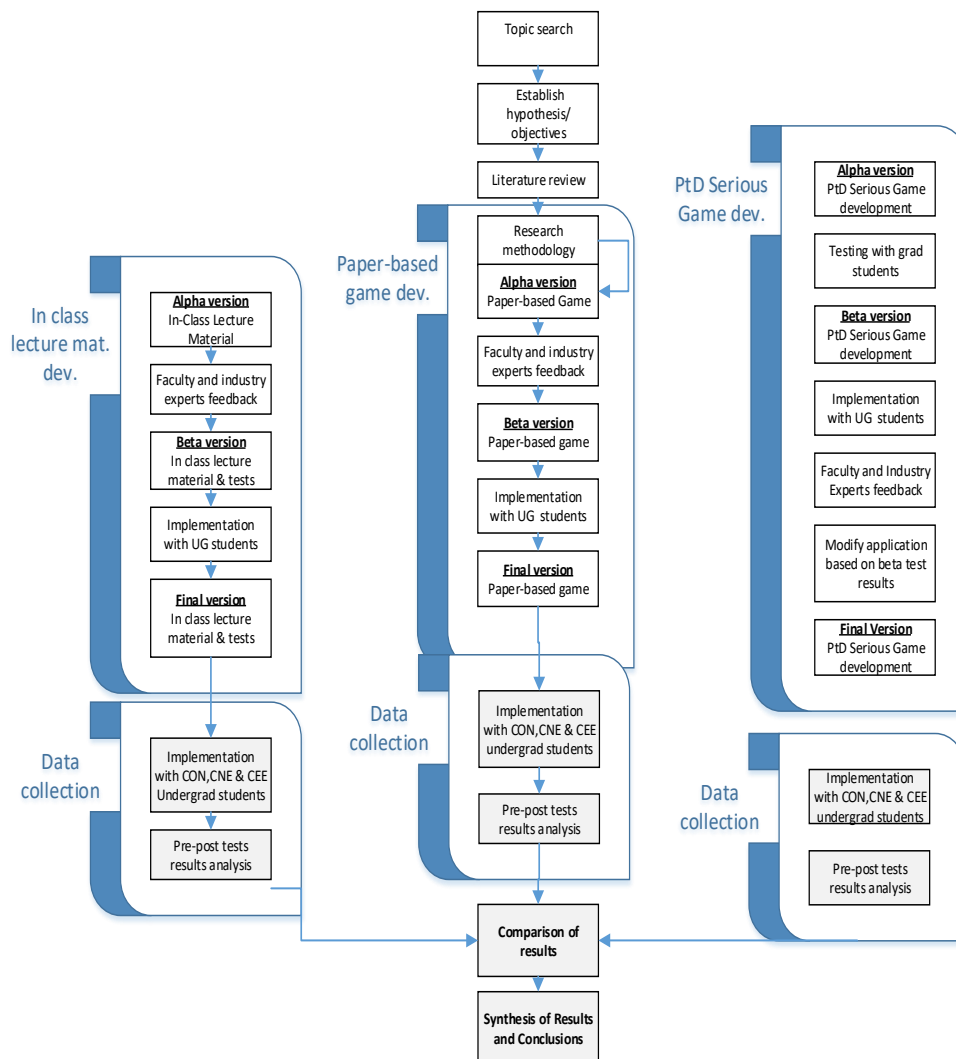
will help to answer specific research questions.

The research methodology selected for this dissertation is quasi-experimental design. In educational interventions, the random assignment of participants to experimental (game) or control groups (non-gamer) is not always possible. In that case, a quasi-experimental design would have to be used (Field & Hole, 2003). Intervention evaluation studies will use a pretest and posttest format. The analysis techniques for the data collected will be descriptive statistical analysis and inferential statistical analysis.



### CHAPTER 3: RESEARCH METHODOLOGY

The purpose of this study is to determine the effectiveness of serious games as an instructional technique. As stated previously, the theoretical structure for serious games rests on constructivism. According to the theory of constructivism, learners build their knowledge through experiences and reflecting on experiences (Piaget, 1955). For most serious games, this theory is applicable.



**Figure 4. Research methodology**

When a serious game is designed on the constructivist approach, it should influence students to build their own reality. For this research, the author developed two versions of the prevention through design game. Both types of games have feedback and gameplay features. Learning, storytelling, and user experience as mentioned in the DPE framework are held constant for the both versions of the serious game.

Figure 4 presents a research methodology adopted to test the effectiveness of the selected pedagogical interventions. Subsequently, research questions are outlined, and research methodology is explained.

### **3.1. Establish Hypothesis /Objectives**

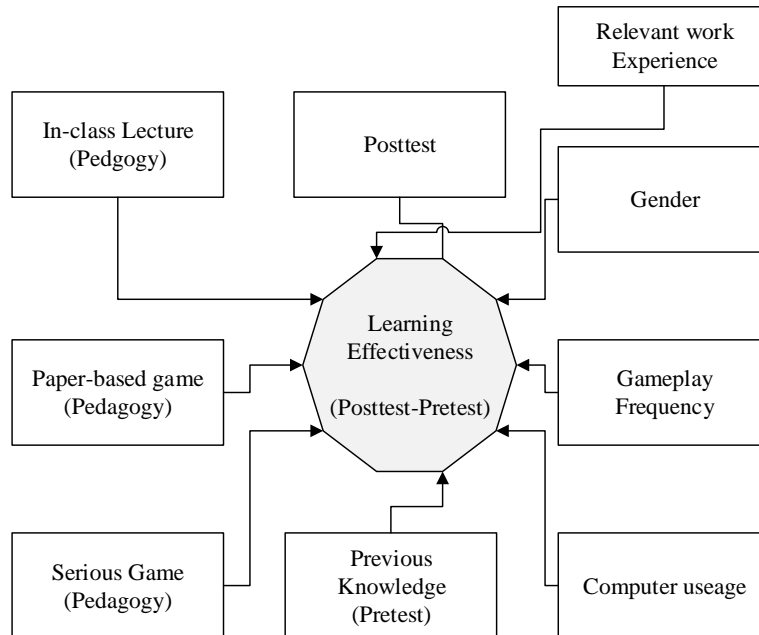
As discussed in Chapter 1, the broader question that this research aims to address is: what is the pedagogical value of the in-class lecture, paper-based game, and serious game to instruct the prevention through design topics to construction engineering and construction management undergraduate students? Since gender, relevant work experience, computer use frequency, and learning game playing experience may have a relationship with learning outcome from a particular pedagogy; therefore, it is important to see their relationship on learning after receiving instruction via lecture, paper-based game, or serious game.

### **3.2. Literature Review**

As discussed in Chapter 2, a wide variety of sources have been described and formed the basis for much of the methodology as discussed in succeeding sections.

### 3.3. Research Methodology

In this section, a theoretical model for pedagogies, variables and the relationship of different variables to learning are described.



**Figure 5. Pedagogical interventions and other covariates that influence learning**

Pedagogical interventions and other covariates that influence learning are shown in Figure 5. In this Figure, the improvement in learning is a dependent variable, which is the difference between posttest and pretest scores that is also called the gain score. The improvement in knowledge was measured in this study using gain score. Alternative hypotheses suggest that the all three pedagogical interventions should positively influence learning. There are also confounding variables that affect learning performance: gender, learning game-play experience, computer use frequency, and relevant work experience. A confounding variable is any variable that is associated with both the

dependent and independent variables, and in practice, it is often difficult to eliminate its effect on the outcome of experimental design (Wood, 2015). In this study, a pretest was conducted to evaluate the prior knowledge before the intervention, and a posttest was administered to assess the effect of the intervention on learning. The variable involved in this study are described below.

### **3.3.1. Dependent Variable**

In this study, the dependent variable is the measure of learning improvement. The learning improvement is also called the gain score. The gain score is calculated by subtracting pretest scores from posttest scores. The posttest score and pretest scores are collected by totaling the test score of content understanding questions. All the six tests (three pretests and three posttests) are shown in Appendix A to Appendix F. These tests are intended to find the total improvement in learning the contents delivered through the three interventions.

### **3.3.2. Independent Variables: Pedagogies**

The pedagogies and their learning significance were studied in Chapter Two. Based on learning theories and scholarly work of researchers, this study describes the followings as independent variables: in-class lecture, paper-based game, and serious game. The importance of each of these is presented below. The use of these pedagogies will be introduced in the last section of this chapter.

#### **3.3.2.1. Serious Game**

Serious games have gained the attention of educators and have been utilized in

some of the following areas to motivate and engage learners, for example, Maths (Habgood, 2007; Ke, 2006), Languages (Johnson & Wu, 2008; Y. Rankin, Gold, & Gooch, 2006) Technologies (Sheng et al., 2007), Science (Squire et al., 2004), Health and Wellbeing (Beale et al., 2007), Social Studies, (Piper et al., 2006), Expressive Arts (D. Wagner, Schmalstieg, & Billingham, 2006), and Religious and Moral Education (Paiva et al., 2005). There is a dire need to investigate the effectiveness of this pedagogical approach for teaching the topics of prevention through design also.

#### **3.3.2.2. Paper-based Game**

It has been said over the ages that a picture is worth a thousand words. We have only one brain, but it is divided into a right hemisphere and a left hemisphere. Each side of the brain appears to be dominant for some faculties. The right hemisphere is more dominant for creative and visual art abilities, and the left side is more dominant for calculations, math and logical abilities (Patricia & Canning-Wilson, 1999). Hence training the two sides of the brain can work together and expand the learning by assimilating the verbal with the artistic faculties. In this study, the paper-based game offers visualization through pictures and cartoons. Mostly, paper-based games include gameplay and visualization of gameplay that enable players to see what is occurring in the game.

#### **3.3.2.3. In-class Lecture**

The instructional method of the lecture is believed to be originated from the medieval period about 1000AD and 1500AD. Even today, students learn in the classroom through instructional materials sources disseminated through lectures. The effectiveness

of lectures has always been questioned, but so far, this is the most dominant form of instruction method in adult education in most parts of the world (Atanga, Abgor, & Ayangwo, 2015).

### **3.3.3. Confounding Variables**

Classic experiments are often performed in a controlled environment, such laboratories to establish the effect of the independent variable on dependent variable only, and no other factors are allowed to undermine the effect of independent variables on the dependent variables. However, in measuring the pedagogical effectiveness of teaching methods, it is often not possible to experiment in a completely controlled environment. Therefore, in this study, the following variables probably influence the gain score, which is the measure of learning effectiveness and the dependent variable of the study.

**Gender:** Historically, literature on games shows that there is an inconsistency between male and female students in their interest to using computer games. Hartmann and Klimmt (2006) found in a survey that females are less interested in video games than males, and when they like to play, they frequently choose different games. However, recent studies on gender and games present different findings. For example, in a study Klisch, Miller, Wang, & Epstein (2012) and Chang, Evans, Kim, Deater-Deckard, & Norton (2014) found that female learners scored higher than males in term of learning performance score and engagement. In addition, according to the Entertainment Software Association (ESA), the number of girl video game players has escalated also. According to ESA, women are 42 percent of all game players. Interestingly, 41 percent of total game

players are adult females, whereas 17 percent of video gaming players are boys of age 17 or younger (The Entertainment Software Association, 2016). These figures indicate that an increasing number of adult females are interested in video game playing in general. Therefore, females might also be interested in learning through serious games.

This study will examine whether both male and female students benefit to the same extent from all three pedagogies. Therefore, gender is treated as a confounding variable and is coded as 1 = Female; 2 = Male.

**Learning Game-playing Experience:** Learning game-playing experience may increase the learning performance of students in the case of serious game intervention. Therefore, the survey, which is part of the pretest, asked students if they ever played video games for learning. Learning game-playing experience question gives two options to respondents, yes or no and a follow-up question asks participants, their perception of the usefulness or learning value of the game if they played.

In this study, the author tries to understand the effect of the confounding variables on gain scores and interaction effects confounding variable on the primary independent variables. The research design contains a dependent variable (gain score), three independent variables (pedagogies), and five confounding variables (gender and learning game-playing experience, computer use frequency, and relevant work experience). The participant data were collected to understand how the independent variables and confounding variables affect the gain score. In the subsequent section of this chapter, the following aspects of this research are outlined:

1. Design of the study
2. Background of the study

3. Interventions: Development of the serious game, paper-based game, and in-class lecture contents.
4. Implementing the independent variables: Pedagogies
5. Pre- and post-test data collection
6. Data collection about confounding variables

### **3.4. Design of Study**

This study has only one dependent variable, and this is called univariate study. A hypothesis testing procedure Analysis of variance (ANOVA) is suggested. ANOVA is a collection of statistical models that compare the significance of mean differences of a dependent variable between two or more groups or interventions (Agresti, 2017). In this study, the gain score is the single dependent variable. In an analysis of variance, a factor is an independent variable. “A study with more than one independent variable is called a factorial design and individual treatment conditions or subdivision of factor that form a factor are called levels of the factor” (Cutting, 2002). In this study, the author has considered the following independent variables:

- Learning game-playing experience (has two levels: yes and no,
- Gender (has two levels: male and female)
- Relevant work experience (has three categories: experience in the field of construction safety, engineering design, or/and construction)
- Computer use per week (has six levels: 6-8 hours, 4-6 hours, 2-4 hours, 2-4 hours, 0-2 hours, and no use)

To determine the main effects of pedagogical interventions, univariate analysis



was conducted. The mean difference of gain score among the pedagogical interventions is called the main effect of the pedagogies. Similarly, when the learning effect of pedagogies may also be due to confounding variables, this is called an interaction. A typical factorial design case is represented in Table 3 shown below (based on W. M. Trochim, 2000).

Table 3 lists the levels of an independent variable, that is, pedagogical strategies and covariates that are, learning game-playing experience. Table 4 presents the way these levels and factors interact to form a factorial design based.

**Table 3. Levels of Independent variable pedagogies and confounding variable learning game-playing experience**

IV: Factor A: Pedagogies	
Level 1	In-class lecture
Level 2	Paper-based game
Level 3	Serious game
IV: Factor B: Learning game-playing experience	
Level 1	Yes
Level 2	No

The two factors create a 3 by 2 factorial design, which is shown in Table 4.

**Table 4. Factors and their levels**

Pedagogies (Factor A)	Learning game-playing experience (Factor B)		
		(Level 1) Yes	(Level 2) No
(Level 1) In-class lecture	Gain Scores	Gain Scores	
(Level 2) Paper-based game	Gain Scores	Gain Scores	
(Level 3) Serious game	Gain Scores	Gain Scores	

The main advantage of the factorial design is that “it not only looks at how each independent variable affects the dependent variable, but also how the combination of the independent variables affect the dependent variable” (study.com, 2017). In this study, factorial design determines the pedagogical interventions’ effect on the learning performance, and it assesses the collective effect of gender, learning game-playing experience, relevant work experience, and computer use frequency on the gain score.

### **3.5. Context of the Study**

The trends in the literature review suggested that millennial students would be one of the prime beneficiaries of serious games. Therefore, the population for this study is construction engineering and construction management students with a significant majority being digital natives (Prensky, 2001b) and millennial students (Elam, Stratton, & Gibson, 2007). Due to cost and time constraints, a sample population will be used in the study. The sample population will consist of construction engineering and construction management students from Arizona State University—a public university.

Classes with 30 or more registered students were identified to participate in this research. One of the classes chosen to take part in the study was in the computer lab because the serious game was required in a computer lab and the other two classes were in regular classrooms because computers were not required for the lecture and paper-based game treatments. The proposed interventions were given to different classes. This research was set up with a quasi-experimental arrangement to isolate the various formats of treatment activity. Proposed courses to implement the treatment activities were Construction Safety (CON/CNE 271) and Working Drawing Analysis (CON 244) courses. The enrolled students in CON/CNE 271 were from the construction management and construction engineering disciplines. Whereas, students in CON 244 were from the construction management discipline only. The reason for the selection of the Construction Safety course was to see the effectiveness of teaching prevention through design topics along with standard construction safety topics covered under OSHA 30-hour course curriculum requirement. The Working Drawing Analysis course was a natural choice for teaching safety in design to construction management students because they learn for the first time how to read drawings developed by designers and engineers. Safety knowledge may help them to see drawings from a safety perspective also. Other than teaching strategies, the process of measuring the effectiveness of pedagogies using the pre- and post-tests method was held as constant as possible among all the treatments.

To measure the effectiveness of pedagogies, a survey/questionnaire methodology was used to compare the differences in student knowledge improvement following an instructional session. The methodology section presents a workflow schedule that describes the steps required to develop, implement and evaluate the SafeDesign game,

paper-based game, and lecture activity. Previous literature was used to establish an inquiry tool that was used to investigate the pedagogical nature of a serious game and other pedagogical strategies being implemented. Specific comparisons were made between the instructional techniques of the lecture, paper-based game reading, and serious game.

The intervention evaluation studies used a pretest and post-test. Since research interest in the field of teaching prevention through design topics is rather recent, therefore no surveys were available in the literature, which could be amended for this study. Therefore, the author prepared a pretest containing survey questions, and this pretest was sent to the Office of Research Integrity and Assurance at Arizona State University for review. The final version of the survey pretest was based on the feedback received from the Office of Research Integrity and Assurance at Arizona State University. The analysis techniques for the data collected will be descriptive statistical analysis and inferential statistical analysis.

### **3.6. Research Treatment Processes**

The prevention through design treatment activities have not traditionally been a part of the course curriculum in construction programs and are described in detail in the sections below.

#### **3.6.1. Treatment 1: Prevention through Design Serious Game Development**

The first step in developing this learning tool was to develop a goal and a list of educational objectives to meet the goal. The goal was to design an engaging serious game that educates students about hazard identification, moreover, control measures. The

following are the educational objectives focused on teaching about prevention through design concepts through the SafeDesign game prototype.

- To familiarize students with the concept of safe design
- To provide students with the experience of identifying risks associated with site location, access to the job site, working at height, excavation, and electric power and implementing control measures
- To give students an understanding to determine which operations meet or fail to meet acceptable safety levels
- To give students the ability to “prevent” accidents through substitution, isolation, protection and personal protective equipment

The objectives were achieved through the selection of several scenarios for the game. The game was developed in the context of learning material and game context; game story and player roles. The gameplay was demonstrated at the start of implementation with CON 244 students. The following section presents the example of such scenarios.

### **Examples of the SafeDesign Game Scenarios**

You are a construction manager, or design engineer (you can choose any role), and your assignment is to identify safety-related design problems and suggest control measures in a given scenario presented. This will offer the opportunity to demonstrate your understanding of safe design development to eliminate possible fatalities and injuries during the construction and operation of a building. An overview of the narrative is as follows:

You are working for a company called Phoenix Builders, and your employer wants you to review a design of an office building and identify safety related problems.

Phoenix Builders is recognized as one of the “safest” corporations in the world and its CEO was recently awarded the “safest business leader of the decade.”

This recognition enables Phoenix Builder to obtain business from government, and tax breaks for its safe construction. Their work involves construction of important structures such as university buildings and stadiums. As you evaluate the following scenarios, you will be rewarded with \$1,000 for each major risk identified and \$500 for suggesting a practical control.



**Figure 6. A typical scenario of the SafeDesign game**

You will make decisions about which material, process, and operation will be unsafe. From a list of options, you can choose a replacement of the material, process or operation. If you fail to identify and an accident happens, your employer could go out of business, and you could lose your job. Your investigation will inform plans to improve the health and safety of the workers. Throughout the mission, you uncover hazards that reveal the weakness in the design process. Your new knowledge will give you better

insight into safe designs and prepare you to explain the reasons behind injuries and fatalities of workers. For example, Figure 6 presents a scenario in which material is stored under power lines. You will be given four options of possible hazards, and you will identify based on your understanding of the scenario.

### **Typical Content for Storyboard**

The core theme of the story will be based on CII's tool to design, construction worker safety, which was developed by Jimmie Hinze and his colleagues in 1997 (John a. Gambatese et al., 1997). The following topics were used to create scenarios.

- Site location and access,
- Material storage options,
- Housekeeping,
- Pedestrian safety,
- Overcrowding,
- Trenching and Excavation safety,
- Formwork erection and removal decisions,
- Use of personal protective equipment,
- Laying underground utilities using trenchless technologies,

### **Work at height**

- Parapet adequacy for fall protection,
- Fragile roofing (skylights, corrugated fiberglass),

### **Electrocution**

- Material storage and overhead power lines,
- Excavation and underground power lines,

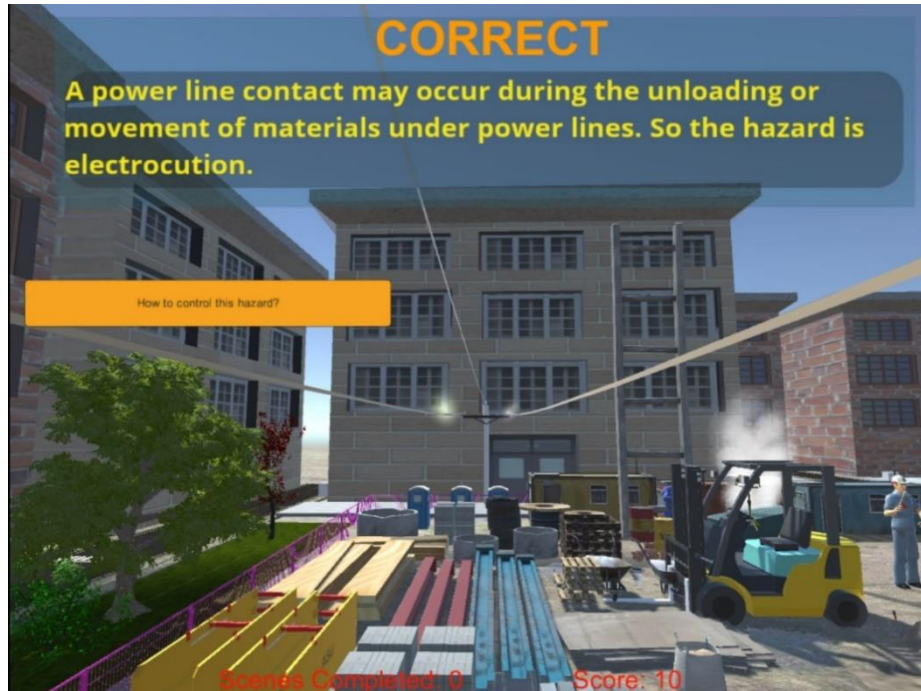


Figure 7. Typical SafeDesign game scenario providing feedback



Figure 8. A typical SafeDesign game scenario presenting hazard control options



Figures 8 and 9 represent two important gameplay options: feedback and selection of controls.

### **3.6.2. Treatment 2: Prevention through Design Paper-Based Game**

To better understand the effectiveness of an alternative pedagogy, a paper-based approximation of the serious game was developed for Treatment 2. After delivering necessary instructions to students how to use the paper-based game, this treatment was implemented with one Working Drawing Analysis (CON 244) class in the spring 2017 semester. The workflow for the development and implementation of this activity includes some of the same tasks that were completed in the SafeDesign game, but without the use of a computing device.

### **3.6.3. Treatment 3: Prevention through Design Lecture**

To understand the benefits of the traditional teaching method, an in-class lecture was delivered in Construction Safety (CON/CNE 271) class in the spring 2017 semester. This helped to illustrate the inherent behaviors of construction engineering and construction management students who might not be interested in a computer game experience.

Students enrolled in CON/CNE 271 were delivered a 50-minute lecture, including discussions about the prevention through design concepts in construction. During this lecture, an overview of the safe design was covered. Moreover, the topics presented were related to the top four hazards in construction, the sources of these hazards and ways to control them through design. The PowerPoint lecture was prepared delivered the content such as facts, statistics, and graphics of the main four reasons for the construction

workers' deaths, which are falling from a height, struck-by falling or flying objects, caught-in or between two surfaces and electrocutions (OSHA n.d.). In this lecture, the author tried to address the learning needs of all students through including facts, graphics, and interactive discussions during and at the end of the lecture presentation.

### **3.7. Designing the Assessment Tools**

To understand the pedagogical value of the SafeDesign game experience, it was necessary to collect appropriate data to qualify and quantify the results of experimental treatment activities. Therefore, assessment tools were developed in conjunction with the development of the application itself. The assessment tools have several different parts intended to elicit data to understand the implications of the implementation of this research. The responses to the evaluations helped to answer several questions, including:

- a) Did the pedagogical interventions help student learning the topics of PtD?
- b) Did students prefer one type of intervention over others?
- c) Did students' gender, learning game-playing experience, computer use frequency, relevant work experience, and gender effect their choice of learning methods?

#### **3.7.1. Pretests**

Pretests containing test identification numbers were used to gather the background information and subject knowledge, which used as baseline information to detect any changes after invention. The intervention activity was implemented two weeks after the pretest. Both the pre- and post-tests contained closed- and open-ended questions related to the safe design principles.

A few questions were requested to obtain targeted demographic information about the students as well as information related to their gender, learning game-playing experience, computer use frequency, and relevant work experience. The questionnaire in this survey provided information about the extent to which students have used computers in the past as well as their experience with serious games. The responses to these assessment tools will help to understand better the students' performance in the interventions

### **3.7.2. Posttests**

After the experimental treatment activities were completed, students took in-class posttest with questions about the prevention through design concepts as well as questions related to their impression of the experience. As with the pretest, the posttest included both closed and open-ended questions to understand better quantitatively and qualitatively the levels of feedback and depth of student understanding. These post-test questions sought student feedback on issues related to format of the activity, perceived value of the activity, and level of enjoyment that students might have while completing the activity. This student perspective helped to provide information about how the class received different treatment activities.

### **3.7.3. Student Feedback**

In addition to asking directed qualitative and quantitative questions in the tests, student feedback was also gathered through informal discussion after the interventions. About ten students who participated in the paper-based and serious game interventions came forward to share their experience. These discussions were not organized as a focus

group meeting. This discussion with students helped to learn about the topics that are not initially covered in assessments.

### 3.7.4. Instructor's Feedback

While implementing the interventions, the instructors of Work Drawing Analysis (CON 244) class and Construction Safety (CON/CNE 271) class acted as observers and provided their perspective related to the learning experience of the students. Instructor's feedback helped to identify other behaviors observed in the treatment activities that were not directly collected in the assessments, and this feedback will contribute to guide future application improvements and identify potential developments for course-specific learning scenarios.

### 3.8. Testing – Pilot Tests

Through the preliminary implementation of the game, the performance of the pedagogical tool was assessed. Five postgraduate students were requested to play the game and identify hazards. The participants were pursuing masters degrees in construction management and construction engineering disciplines. The participants had

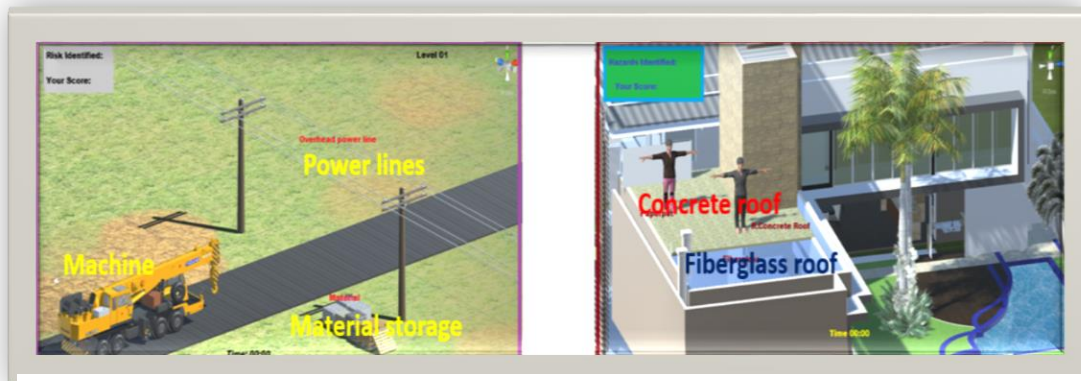


Figure 9. Typical scenarios on electrocution and fall from height (pilot test)

not taken a course or training in construction safety before. Therefore, this might be the first exposure to the construction safety related training material.



**Figure 10. Typical scenarios on slip, trip & fall and structural design defects (pilot test)**

### **3.8.1. Results of the Pilot Testing**

The results indicated that the participants were able to identify 70 percent of the hazards present in the hypothetical construction scenario. The participants were also able to suggest the controls to eliminate the identified hazards. The hazards identified were related to falling from a height, trip and slip, and electrocution.

Based on these results, the game was improved further to include better graphics 3D and increased difficulty levels so that gameplay would become fun as well as challenge.

### **3.9. Data Processing and Data Entry**

All the raw data were typed into a Microsoft Excel spreadsheet, after cleaning the data; it was transferred to statistical package IBM SPSS 23. The data had three outliers,

which were replaced with the closest values using a concept called Winsorization. Winsorizing suggests replacing the smallest of X values with the next smallest value (Wilcox, 2013). Researchers consider using Winsorizing because it conserves the information that a case had the highest (or lowest) values in distribution, but keeps against some of the unwanted influence of outliers (Salkind, 2010). In order to code the data in the SPSS file, codes were created, and codes were assigned to each answer of the survey. For example, female =1 and male =2. Thus, all the human-readable-survey data were converted to machine-readable data. Simply, a unique code was assigned to a particular question.

### **3.9.1. Code Verification**

For this study, IBM SPSS 23, a computer program was used to enter the data and perform analysis of the data. In order to ensure the accuracy of the data, a double-entry method was used. The double-entry technique allowed matching the second value entered against the first value and identifying any mismatches. Only four mismatches were found in the data set, which were corrected after verifying from the pre and post-test sheets.

With the help of the SPSS program, the author also verified the validity of the ranges of codes entered into SPSS data view and variable view. If a code was outside the valid range for that particular answer, it was considered incorrect and required to be corrected.

### **3.10. Data Analysis**

A total number of 118 students from three sections of construction engineering and management program participated in the study. Out of 118, only 88 students

completed all the steps of the data collection. Following are the key steps the students were required to complete to consider their responses for further analysis.

- a) Step 1. Taking the pre-test and survey
- b) Step 2. Participating in one of the interventions: lecture, paper-based game, or serious game
- c) Step 3. Completing the posttest and survey

Out of 118, 25 participants did not complete both pre- and post-tests. Also, five students participated in more than one intervention, hence their first participation scores were only considered. The remaining 88 participants' data were considered for the analysis.

### **3.11. Threats to Internal and External Validity**

Bellini and Rumrill Jr. (2009) highlighted that for the external validity of research several threats are present, including population validity; it means that how representative is the sample of the populations and how widely does the finding apply. The current research activity is a pilot study with a relatively small sample size. Therefore, the author suggests not generalizing the conclusions before conducting more tests with a large sample size.

The second type of external threat is called ecological validity. There is an agreement among scholars that the “interaction of pretesting and treatment comes into play when the pretest sensitizes participants so that they respond to the treatment differently than they would with no pretest” (Dimitrov & Rumrill, 2003). For example, the interaction effect of testing where participants took a pretest before the intervention,

and it may affect the results. The third type of external threat is the Hawthorn effect, which suggests that students were aware that they were going to participate in an experiment and their behavior might be different from normal. To address the Hawthorn effect, students were given freedom to refuse to participate and leave anytime.

In an experimental design where pre- and post-tests are involved, a threat to internal validity also exists when questions on the pretest and posttest are identical. This is because a pretest may inform participants in unexpected ways and their performance on the posttest may be due to the pretest, not to intervention, or, a combination of the pretest and invention (Michael, 2002). This phenomenon is called priming the subjects toward the posttest (Shadish, Cook, & Campbell, 2002; W. M. K. Trochim, 2005).

When the pretest and the posttest are administered in a short time frame, students might get prepared because of the questions and topics asked on the pre-test. In this study, to reduce the chances of getting primed due to pretest, the researcher gave the pretest two weeks before the intervention and posttest. In both tests, content understanding questions were kept the same. The only motivation related questions were changed. This eliminates the internal threat to the validity of the study, which will be otherwise susceptible to instrumentation threat.

First, the testing threat was minimized by having the time distance between pretests and posttests. Second, the content understanding questions were left unchanged to control the instrumentation threat.

### **3.12. Gain Scores**

One way to estimate the learning effect of treatment in a pretest-posttest design is



to determine gain score. The gain score is calculated from the following formula: Gain score = posttest score – pretest score. In order to find a statistically significant effect on learning, two popular tests were conducted. First, an analysis of covariance (ANCOVA) uses posttest scores as the dependent variable, and pretest as a covariate. Second, an analysis of variance (ANOVA) that uses gain score as a dependent variable and any other variable such as interventions, gender, learning game-playing experience, and computer use frequency as an independent variable. In this study, the author applied ANOVA to gain score instead of ANCOVA. A large number of research publications (Cribbie & Jamieson, 2004; Dimitrov, Rumrill, & Rumrill Jr, 2003) suggest the use of ANOVA on gain score over ANCOVA. ANOVA finds if there are any statistically significant differences between gain score means of the interventions.

### **3.13. Summary**

Gain scores of three pedagogies were identified as the main effect to be studied in this research. This chapter discussed the three pedagogical approaches as an independent variable. While gender, learning game-playing experience, relevant work experience, and computer use frequency were considered as confounding independent variables and covariates. The gain score was calculated by subtracting the pretest score from the corresponding posttest score of each participant. In this study, the gain scores were considered as a dependent variable. To address the first research question of the study regarding the effectiveness of pedagogical approaches three hypotheses were stated and to study the second research question on the effect of confounding variables on learning performance three more hypotheses were framed. In this study, these hypotheses were

formed as alternative hypotheses.

Hypothesis 1: An in-class lecture positively impacts learning.

Hypothesis 2: A paper-based game positively impacts learning.

Hypothesis 3: A serious game positively impacts learning.

Three more alternative hypotheses were framed to study the impact of confounding variables on learning performance.

Hypothesis 4: Gender will make an impact on learning.

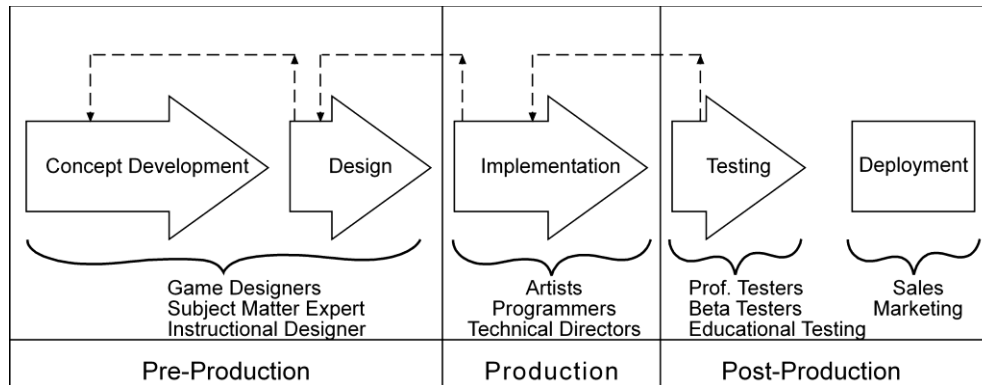
Hypothesis 5: Previous knowledge and relevant work experience will positively affect learning.

Hypothesis 6: Computer use frequency and previous game playing experience will positively impact learning scores.

To test these hypotheses, an in-class lecture, a paper-based game, and a serious game were developed and implemented. The purpose of the interventions was to teach prevention through design. These interventions were used to find the effect of a teaching approach on learning performance of students. A total number of 118 students from three classes at Arizona State University participated in the research study. Out of 118, 88 students finished all the required steps of data collection. The subsequent chapter presents the lessons learned from the serious game development process, which can help instructors and educators to rapidly author serious games to test the effectiveness of those tools in different fields. Chapter 5 describes the results of the data analysis to understand the pedagogical implications of findings.

## CHAPTER 4: LESSONS LEARNED FROM SAFEDESIGN GAME DEVELOPMENT

This research aimed to find the pedagogical value of serious games. A core component of this work was to develop a prototype application, which is named as SafeDesign game. This chapter explores the process of creating the SafeDesign game and documents the challenges associated with the development of a serious game. The general process for creating this type of application is shown in Figure 11. In Chapter 2, the concept of game development based on Design, Play, and Experience (DPE) framework has been outlined, and in Chapter 3, the testing process has been presented. In this Chapter, lessons learned from the SafeDesign game development process has been documented.



**Figure 11. General process of serious game development** (Purdue University, 2007)

Typically in the serious game development process, a team comprising of computer programmers, artists, designers, subject matter experts, directors, and pedagogy specialists work (Purdue University, 2007). After the development, for testing and marketing, a separate team is employed. However, for this study, the goal was to develop a proof-of-concept application for a pilot study. Therefore, the author performed all the roles mentioned above.

#### 4.1. Game Development Platform

After selecting the learning content for the game, the first step was to create a storyboard. This process enabled the author to understand the requirement of game assets. This was followed by the selection of a game development engine. Although there are several games, development engines available with 2D and 3D game development capabilities, the author decided to choose a development engine for this study based on the following criteria.

- 1) Licensing cost per seat the game development engine
- 2) Availability and cost of training material
- 3) Scripting requirement
- 4) Learning time required
- 5) Hardware requirements
- 6) Flexibility to export on different platforms such as Mac, Windows, Mobile platforms, etc.
- 7) Ease of use

After research and discussion with game developers, the author selected the Unity 3D game development engine. Unity has several advantages over other commercially available game engines. For example, 1) Unity offers license for educational use; 2) the Unity asset store offers visual programming tools which are helpful in reducing scripting need; 3) availability of free video tutorials to learn the game development engine and scripting language; and 4) the Unity game can be exported to any platform (computer operating system). Table 5 provides a list of most prominent game development engines, which have their pros and cons.

**Table 5. Game development engines**

Game Engine	Programming requirement	2D or 3D	Operating System	Exports to
Construct 2	No	2D (All Genres)	Windows	Desktop, Consoles, Mobile, Web
GameMaker: Studio	No	2D (All Genres)	Windows	Desktop, Consoles, Mobile, Web
Unity	Yes	2D + 3D (All Genres)	Windows, Mac	Desktop, Consoles, Mobile, Web
Unreal Engine	Yes	3D (All Genres)	Windows, Mac	Desktop, Consoles, Mobile
Clickteam Fusion	No	2D (All Genres)	Windows	Desktop, Mobile, Web
Stencyl	No	2D (All Genres)	Windows, Mac, Linux	Desktop, Mobile, Web
GameSalad	No	2D (All Genres)	Windows, Mac	Desktop, Mobile, Web
PICO-8	Yes	2D (All Genres)	Windows, Mac, Linux	Desktop, Web
CryEngine	Yes	3D (All Genres)	Windows	Desktop, Consoles
PlayCanvas	Yes	2D + 3D (All Genres)	Browser (Windows, Mac, Linux, Mobile)	Desktop, Mobile, Web
Godot Engine	Yes	2D + 3D (All Genres)	Windows, Mac, Linux	Desktop, Web
Superpowers	Yes	2D + 3D (All Genres)	Windows, Mac, Linux	Desktop
Torque 2D/3D	Yes	2D + 3D (All Genres)	Windows	Desktop, Consoles, Mobile

In the production process, the first step is to learn how to use a game development engine. Following section describes the author's experience of programming which is a fundamental requirement for 3D game development.

#### 4.2. Coding

All 3D game development engines require programming skills of a game developer. The most commonly used programming languages supported by game development engines are C# (C-sharp) and JavaScript. The Unity engine supports both

languages. The tutorials for learning coding are also available free of cost on the Unity website, and the tutorials are available from beginner level to expert level (Unity, 2017). Despite the availability of learning material, the author considers coding is a tedious and time-consuming task for a non-programmer.

### **4.3. 3D Assets**

To develop 3-D graphics, the author used the SketchUp Pro program available for a cost of \$50 for educational use compared to \$695 for professional use. There are several challenges related to exporting the models/assets from SketchUp to the Unity program such as, if not properly created and exported, the SketchUp assets create many useless faces of an object resulting in a drop in game performance. Therefore, the author tried to create low-poly assets to achieve a smooth game performance, keeping in view the system specifications of the available computers installed in the lab at the Del E. Webb School of Construction, Arizona State University, where this serious game intervention was tested.

Besides the Unity asset store, several websites are selling 3D assets. Most of the assets required for the game were available for purchase for a price ranging from \$5 to \$200. Also, a few free resources were available on the asset store of Unity (Unity, n.d.). Most assets, including models of construction equipment, construction workers, construction tools, construction material, and building were obtained free of cost from 3D - SketchUp Warehouse (SketchUp, 2017).

### **4.4. Using Unity Assets to Partially Avoid Coding**

The Unity Asset Store hosts a variety of packages called assets, which provide

productivity and ease for non-programmers as well as professionals. These packages are reusable and can be implemented without coding. The limitation is that one needs to design and develop a game around those available packages and if additional functionality is required then coding is the only way forward. For the SafeDesign game, several packages were used to save time and improve functionality. The list of the packages is given below.

- *Urban Construction Pack*: Construction equipment and material assets.
- *Unity4.6.PlayMaker*: Quickly makes gameplay prototypes, A.I., behaviors, animation graphs, interactive objects, cut-scenes, walk-throughs.
- *DialogueSystem*: The Dialogue System for Unity provides support to add professional quality dialogue to the projects.
- *EasyRoads3D*: The easy way to create roads in Unity and deform the terrain object accordingly.
- *Mesh Baker*: Combine meshes and materials to reduce draw calls.
- *Rain and Snow Particle Prefab*: The tools create snow and rain effects.
- *WayPointSystem*: Waypoint System allows to create paths right within the editor, then tell any game object to follow the path via scripts.
- *Unity-NPC-Chat Dialogue-Master*: This helps to add dynamically controllable dialogue, notifications, and events to any scene. Manage dialogue, notifications, trigger events based on collision areas.

#### **4.5. Lessons Learned**

Generally, the development of a serious game combines the skills of numerous

disciplines, from subject matter experts on the topic being taught; to story developers, game designers, and software developers; to instructional designers, educational assessment scientists, and others (Strzalkowski & Symborski, 2017). However, in order to conduct a prototype testing in a formal education setting, the chances of availability of all the resources mentioned above are not common. Therefore, a researcher or instructor would like to know the process of game development to use the promising technology of the serious game. Therefore, the researcher has enlisted lessons learned to provide guidelines and take away points to assist game development practitioners in their future efforts to create effective serious games.

#### **4.5.1. Concept**

As a designer, make an initial concept of what type of game can help improve the learning of a particular topic or subject. Games range from board games to computer games. This will contribute to understanding the requirements of your game development process.

#### **4.5.2. Pre-Production**

Plan what resources are needed to develop a game. For example, software and hardware requirement, alpha and beta testing, etc.

#### **4.5.3. Game Development Engine**

There are many serious game authoring tools. A list of most commonly used game development engines is provided in this chapter (Table 5). The most popular game engine is Unity 3D because it is free of cost for individual and educational use. There is



no shortage of learning resources for the Unity 3D game engine. One can use online tutorials developed by Unity and the other training resources produced by various game developers. The availability of the enormous amount of information to learn the program is also a challenge to find appropriate training material. The author suggests starting with the Unity 3D official training material, which is also free of cost.

#### **4.5.4. 3D Game Asset Development**

Game assets include everything that goes into the game such as models, textures, sound, and scripts (Llopis, 2004). Generally, 3D game assets are not free of cost, and the cost ranges from \$5 to \$250. The game assets can make or break the development of a game. One best place to find such resources free of cost is the 3D Warehouse - SketchUp. One can also create or modify 3D assets (De Jongh, 2011). The disadvantage of using assets exported from SketchUp is that they are heavy due to polygon and triangles used in creating these assets, and if special care is not taken while creating a model by keeping the geometry minimum, it influences game's performance negatively. Other tools like Blender produces smooth assets, but intensive training is required to proceed high-quality game assets.

#### **4.5.5. Audio Assets Developments**

There are a few free audio resources available these can be searched via Google search engine, but other high-quality audio resources are for purchase only. The researcher suggests using the voice of students to create an audio effect to give a more personal connection to the game.

#### **4.5.6. Hardware Requirements**

Developing a game can be a challenging task with a computer of the low specifications. Therefore, Unity suggests using GPU, which is a graphics card with DX9 (shader model 3.0) or DX11 with feature level 9.3 capabilities. The price of the graphics card is about \$200. Other recommended components of the PC build for game development are CPU Intel Core i7-7700 3.6GHz Quad-Core Processor, Gigabyte GA-B250M-D2V Micro ATX LGA1151 Motherboard, 16GB (2 x 8GB) DDR4-2400 Memory, 256GB 2.5" Solid State Drive, and Zotac GeForce GTX 1070 8GB AMP! Edition Video Card (Tom's Hardware, 2017). The computer with all the specification will cost around \$2,000.

#### **4.5.7. Programming language skill requirement**

Game development requires the knowledge and skills of programming languages such as C/C++, C-sharp, JavaScript (Kirriemuir, 2002). Learning of programming skills can be a frustrating and time-consuming for many non-programmers. Fortunately, computer scientists have developed visual programming packages where programming involves using small rectangles with built-in codes to be moved and placed in a particular order to create the desired function as shown in Figure 12. The researcher has mostly relied on such assets such as PlayMaker to make game development relatively fast and



artists. Such requirements can make game development a costly investment that many educational institutions are not willing to spend in the absence of a convincing evidence of the effectiveness of a particular game. Therefore, the authors critically analyzed the state of the art resources for game development and delineated guidelines for lecturers and trainers to create serious games on their own, without the need for specific programming skills. This chapter also offers insights for instructors on what are the low-cost or free resources to author serious games for education rapidly.

## CHAPTER 5: ANALYSIS OF DATA

### 5.1. Introduction

Many anecdotal pieces of evidence support the use of games for teaching and learning purposes. The aim of this research is to establish whether serious games increase learning, and then to determine the effect of gender, learning game-playing experience, relevant field experience, and computer use frequency on learning performance. In this chapter, various quantitative analyses of the data are described. The effect of the three independent variables—serious game, paper-based game, and in-class lecture—was determined using a one-way Analysis of Variance (ANOVA) between subjects fixed factor. To find the learning effect of for confounding variables— learning game playing experience, computer-use frequency, gender, and relevant work experience —factorial ANOVAs were conducted.

### 5.2. Demographics of the Participants

Demographic details of participants are given in Table 6. The total number of participants was 118, but 25 of them did not complete both pre- and post-tests. This situation left author not being able to measure the learning performance of 25 participants as both pre-and posttest scores are required to calculate the gain score. Five more responses were not considered for further analysis because these students participated in more than one intervention. Therefore, their second-time participation scores were not considered for further analysis and this left with 88 valid responses, which formed the basis of conclusions in this study.

**Table 6. Student demographics**

Total number of participants	118
Total number of participants who completed both pre- and post-tests	93
Participants who did more than one intervention	05
Valid participants	88
Participants' gender	
Number of female participants	17
Number of male participants	71
Participants and Interventions	
Number of valid participants in serious game group	28
Number of valid participants in the paper-based game	34
Number of valid participants in the in-class lecture	26

### **5.3. Statistical Analysis**

The following sections present various statistical analyses performed in this study and the results of those tests. In this research, pre- and post-tests were used to measure the learning.

#### **5.3.1. Paired Samples T-test**

The paired samples t-test also called a dependent t-test compares the two means that are of the same person or object (Nolan & Heinzen, 2011). The two statistical means typically are measured at two different times such as pretest and posttest scores of each subject (Rubin, 2009). In this study, the purpose of a paired-samples t-test is to find whether the pedagogical interventions influenced students' learning through the difference in the pretest vs. posttest scores. If there is no improvement in scores from the pretest to posttest, then there is no purpose of additional statistical exploration, since the intervention(s) did not improve student-learning performance. Conversely, if there is an improvement in the scores from the pretest to posttest, which showed the intervention did improve learning, and hence it is important to find where this enhancement of learning

comes from that means which variable is the cause of the enhancement. To determine the differences, an Analysis of Variance (ANOVA) should be performed. Thus, a paired samples t-test needs to be conducted first to see if there is a significant difference between the pretest and posttest scores. The findings of the paired sample t-tests for each intervention are presented in Table 7 to Table 9.

**Table 7. Paired sample t-tests of the in-class lecture's pre- and post-test scores**

Pair		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
1	Posttest - Pretest	7.57	16.92	3.32	.738	14.41	2.82	25	.031

**Table 8. Paired sample t-tests of the paper-based game's pre- and post-test scores**

Pair		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
1	Posttest - Pretest	1.79	27.27	4.68	-7.72	11.31	.384	33	.704

**Table 9. Paired sample t-tests of the serious game's pre- and post-test scores**

Pair		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
1	Posttest - Pretest	16.43	21.91	4.14	7.932	24.92	3.97	27	.000

It is evident from the paired samples t-test results that there was a statistically significant difference in the mean pretest and post-test scores of the in-class lecture and

the SafeDesign game intervention. The average difference between posttest and pretest scores are  $M = 16.43$ ,  $SD = 21.91$  for the SafeDesign game, and  $M = 7.57$ ,  $SD = 16.92$  for the lecture. These results propose that the SafeDesign game positively affects learning performance. When students played the serious game, their learning performance improved as shown in the posttest scores. Furthermore, there is a positive correlation ( $r = 0.294$ ) that indicates that the students who performed better on the pretest also performed better on the posttest. These findings are in congruence with earlier studies in this field (Andreu-Andre & Garci, 2011; de-Marcos, Garcia-Lopez, & Garcia-Cabot, 2016; Dieleman & Huisingh, 2006; Mansureh Kebritchi, Hirumi, & Bai, 2010; Kwon & Lee, 2016; Papastergiou, 2009) which have examined the effect of educational computer games on learning performance.

In case of the in-class lecture, there was also a significant improvement in learning also. The correlation was positive ( $r = 0.415$ ). The concluding chapter of this dissertation explains the significant results of this study in the light of previous research studies.

The results also indicate that there was no statistically significant learning when the paper-based game was implemented. The scenarios were presented through illustrations very similar to those used in the serious game. One explanation for the poor performance is that perhaps these illustrations and the storyline in the paper-based game did not help student learning; rather, diverted students' attention. Researchers like Weidenmann pointed out that there is a good reason to doubt the benefits of pictures in the educational text (Weidenmann, 1989). He said learners would often consider illustrations superficially and inadequately, failing in achieving any contribution to



learning.

#### **5.4. Analysis of variance**

As mentioned earlier, three research questions are being answered through six research hypotheses. The hypotheses are stated below:

Hypothesis 1: An in-class lecture will positively impact learning.

Hypothesis 2: A paper-based game will positively impact learning.

Hypothesis 3: A serious game will positively impact learning.

Three more alternative hypotheses were framed to study the impact of variables on learning performance of students.

Hypothesis 4: Gender will make an impact on learning.

Hypothesis 5: Previous knowledge and relevant work experience will positively impact learning.

Hypothesis 6: Computer use frequency and previous game playing experience will positively impact learning.

To test the study's research hypotheses, the researcher looked for the dependent variable, which is posttest score minus the pretest score, known as the gain score. Since the hypotheses indicated above are directional, a one-way ANOVA between subjects to compare the effect of three pedagogical interventions on student learning. Table 10 presents group means, standard deviations of the gain score, descriptive statistics, and analysis of variance summary.

**Table 10. Descriptive statistics of the gain score**

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Lecture	26	7.57	16.922	3.319	.74	14.41	-19	41
Paper-based Game	34	1.79	27.274	4.677	-7.72	11.31	-61	65
Serious Game	28	16.43	21.913	4.141	7.93	24.93	-36	59
Total	88	8.16	23.482	2.503	3.18	13.13	-61	65

28 participants in the serious game intervention group had an average gain score of 16.43 ( $SD = 21.92$ ); 26 participants in the lecture intervention group had an average gain score of 7.57 ( $SD = 16.922$ ) and 34 participants in the paper-based game group earned an average gain score of 1.79 ( $SD = 27.274$ ). The effects of the interventions, serious game and lecture, therefore, were found to be significant.

**Table 11. Analysis of Variance**

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3301.127	2	1650.564	3.141	.048
Within Groups	44671.107	85	525.542		
Total	47972.234	87			

**Table 12. Multiple group comparison-post hoc test**

(I) Intervention	(J) Intervention	Mean Difference (I-J)	Std. Error	Sig.
Lecture	Paper-based Game	5.779	5.972	.599
	Serious Game	-8.855	6.244	.336
Paper-based Game	Lecture	-5.779	5.972	.599
	Serious Game	-14.634*	5.850	.038
Serious Game	Lecture	8.855	6.244	.336
	Paper-based Game	14.634*	5.850	.038

\* *The mean difference is significant at the 0.05 level*

There was a significant effect of the interventions on learning at the  $p < .05$  level

for three interventions,  $F(2, 85) = 3.141, p = .048$  (Table 12). Post hoc comparisons using the Tukey HSD test (Table 13) indicated that the mean gain score for the serious game intervention ( $M = 16.43, SD = 21.91$ ) was significantly different from the paper-based game ( $M = 1.79, SD = 27.27$ ). However, the in-class lecture ( $M = 7.57, SD = 16.92$ ) did not significantly differ from the serious game and paper-based game. Taken together, these results suggest that the serious game has a significant effect on learning.

Particularly, these results hint that when a serious game is used learning improves.

However, presenting scenarios on paper, perhaps confused the students, causing a drop in learning performance. In this study, when the lecture was delivered the overall score also improved. The current results suggest that the lecture and serious game for teaching safety positively augment learning, and using a paper-based game for teaching concepts of safety do not improve learning.

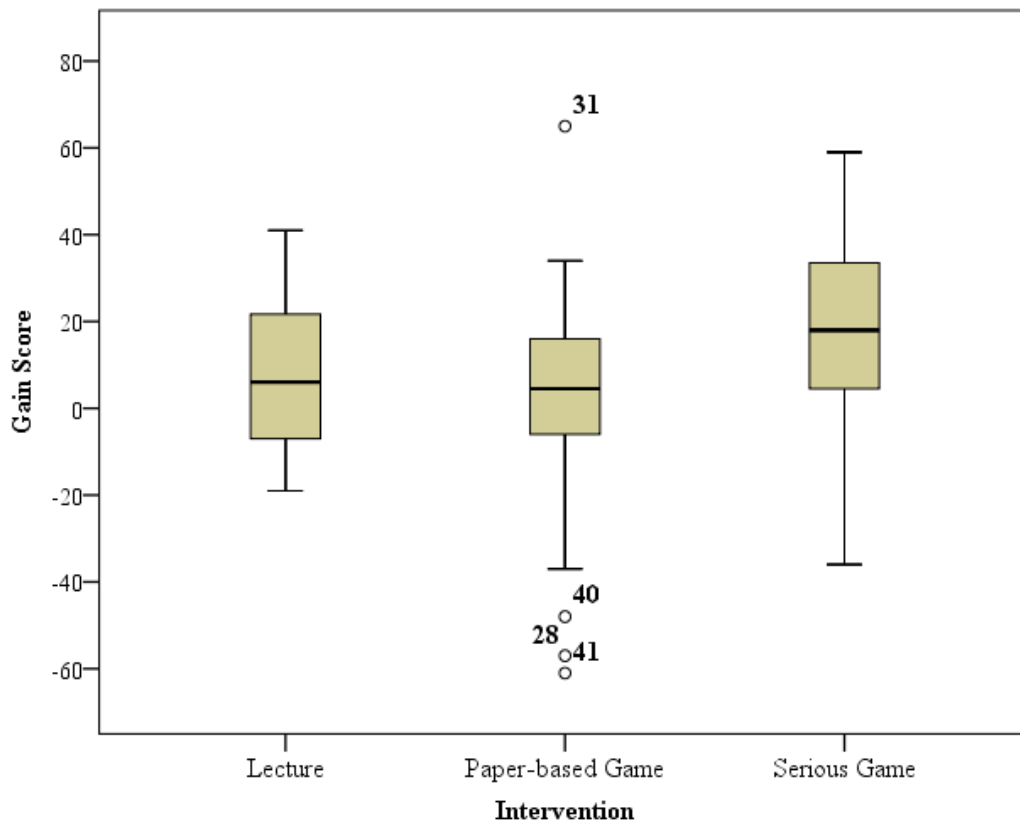
Table 10 presents the descriptive statistics of the gain score, which shows that a serious game such as the SafeDesign game causes a significant improvement in learning demonstrated by improved gain scores.

Using the Tukey test a multiple group comparison of mean gain scores of three pedagogical interventions was performed. The results of the Tukey test are presented in Table 12.

A One-Way Analysis of Variance is used to check the equality of three or more means of samples (Chernick & Friis, 2003). There are three assumptions for the test, and these are: 1) the distribution of gain scores follows a normal distribution, 2) the samples must be independent, and 3) the variances of gain scores must be equal. The first condition was tested through plotting a histogram and found that the data were normally

distributed. The second assumption was met because the participants in each intervention group are independent. In addition, the third one is that groups have nearly equal variance on the dependent variable. In order to check the equal variance assumption, Levene's test of homogeneity of variances was performed. The result of Levene's test shows that the significance is 0.359, which is higher than 0.05 significance level, and it can be interpreted as the variances are almost equal. If variances are not equal, other tests should be used.

Figure 13 provides a chart of the ranges of mean gain scores of student learning in the three pedagogies. The box plot shows that the students in paper-based game intervention performed so different as compared to other two interventions that resulted in extreme values and four mild outliers marked with a circle (o).



**Figure 13. Gain score range of pedagogical interventions**

The results of ANOVA tests for the interventions were compared with  $\alpha = 0.05$ , the P-values of the in-class lecture and serious games are notably less than alpha ( $\alpha$ ), it is safe to accept hypotheses one and three that the in-class lecture and serious game will positively impact learning. When the P-value of the paper-based game is compared with alpha ( $\alpha$ ), it is safe to reject the hypothesis 2, that paper-based game intervention will positively impact the gain score of the participants.

### **5.5. Factorial Design Analysis**

In order to find the impact of the confounding variables—gender, learning game-playing experience, computer use frequency, and relevant work experience— on learning performance of any of the pedagogical interventions, individual factorial design analysis was conducted and outcome of analysis helped to find out the main effects and the interaction effects of these covariates or confounding variables. Precisely, the purpose of the factorial design analysis was to address the following research questions:

1. Are there significant mean differences in achievement scores between male and female participants?
2. Are there significant mean differences in achievement scores between who have learning games experience and who has not?
3. Are there significant mean differences in achievement scores between students with high computer usage and low computer usage?
4. Are there significant mean differences in achievement scores among students with different levels of relevant field experience, and student with no experience?

## 5.6. Gender

A two-way analysis of variance, which is also called Factorial Analysis, was conducted to find the effect of interventions and gender on the gain score and the combined effect of gender and intervention on the gain score. A total of 17 female participants and 71 male participants completed all the intervention sessions. The mean gain scores and standard deviation of male and female participants in all three pedagogies are shown in Table 13.

**Table 13. Descriptive statistics dependent variable: gain score**

Dependent Variable: Gain Score				
Intervention	Gender	Mean	Std. Deviation	N
Lecture	Female	9.90	20.312	6
	Male	6.88	16.309	20
	Total	7.57	16.922	26
Paper-based Game	Female	5.75	27.296	8
	Male	.58	27.690	26
	Total	1.79	27.274	34
Serious Game	Female	33.00	8.718	3
	Male	14.44	22.258	25
	Total	16.43	21.913	28
Total	Female	12.02	23.838	17
	Male	7.23	23.472	71
	Total	8.16	23.482	88

Three female participants in the serious game intervention group had average gain scores of 33 ( $SD = 8.718$ ); 25 male participants in the same intervention group had an average gain score of 14.44 ( $SD = 232.26$ ). It indicates that female participants' performance was very high. In all three intervention groups, 17 female participants earned an average gain score of 12.02 ( $SD = 23.84$ ), and the 71 male participants scored 7.23 ( $SD = 23.47$ ). The effects of the gender on the gain score, therefore, were not

statistically significant.

Table 14 presents the interaction effects of gender and the pedagogies. The result indicates that the interaction effect between gender and pedagogical interventions on the gain score was not statistically significant,  $F(2, 82) = .425, p = .655$ . The main effect of gender,  $F(1, 82) = 1.790, p = .185$ , was not statistically significant.

**Table 14. Tests between-subjects effects: gender and intervention's effect on gain score**

Dependent Variable: Gain Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4429.771 <sup>a</sup>	5	885.954	1.668	.151
Intercept	6604.402	1	6604.402	12.438	.001
Intervention	3161.836	2	1580.918	2.977	.056
Gender	950.274	1	950.274	1.790	.185
Intervention * Gender	451.137	2	225.568	.425	.655
Error	43542.464	82	531.006		
Total	53828.830	88			
Corrected Total	47972.234	87			

a. R Squared = .092 (Adjusted R Squared = .037)

Table 15 indicates the further in-depth analysis to find the effect between male or female participants and the interventions on the gain score. There is not a significant effect on the gain score.

**Table 15. Pairwise comparisons**

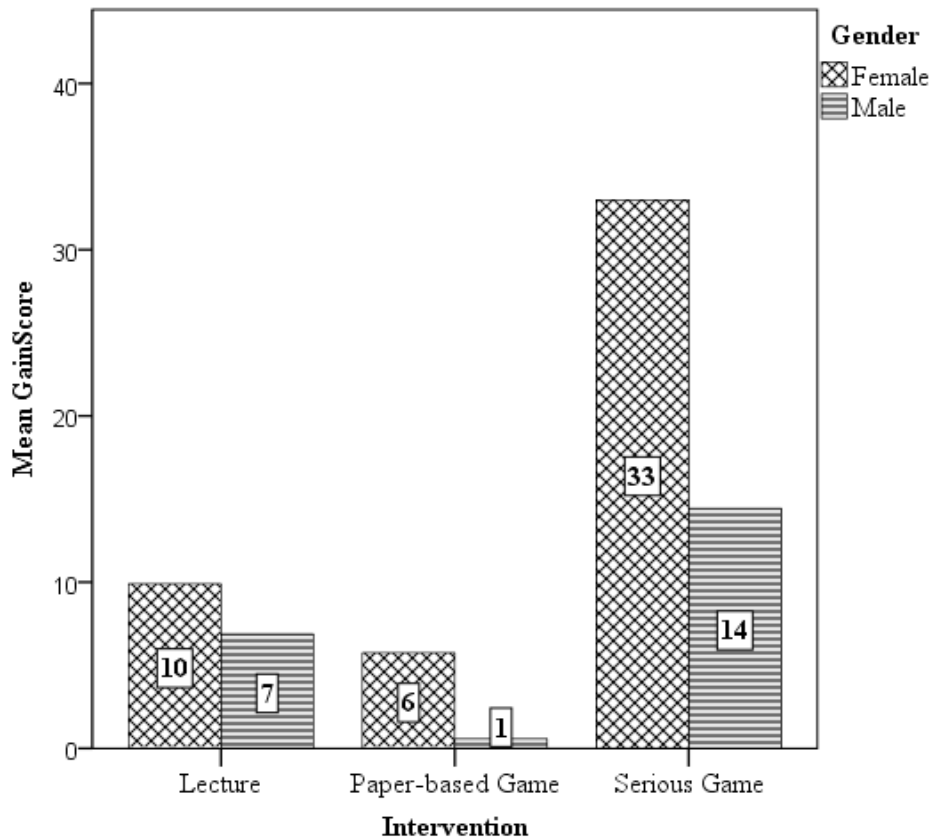
Dependent Variable: Gain Score

Intervention	(I) Gender	(J) Gender	Mean Difference (I-J)	Std. Error	Sig. <sup>a</sup>	95% Confidence Interval for Difference <sup>a</sup>	
						Lower Bound	Upper Bound
Lecture	Female	Male	3.025	10.726	.779	-18.313	24.363
	Male	Female	-3.025	10.726	.779	-24.363	18.313
Paper-based Game	Female	Male	5.173	9.317	.580	-13.361	23.707
	Male	Female	-5.173	9.317	.580	-23.707	13.361
Serious Game	Female	Male	18.560	14.080	.191	-9.449	46.569
	Male	Female	-18.560	14.080	.191	-46.569	9.449

Based on estimated marginal means

<sup>a</sup> Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Figure 14 is a chart of the mean gain scores obtained by male and female participants for three interventions.



**Figure 14. Chart of mean gain scores of three interventions based on gender**

From the chart, it is evident that the female participants performed better than the male participants in all three intervention groups. Because of the small number of female participants (17 vs. 71), the results are not statistically significant. With a P-value of 0.425 not less the designated alpha ( $\alpha$ ) value, it is safe to say that gender has no impact on gain scores.

### 5.7. Age

The average age of the participants was 20.8 years. The average and extreme



values for the age of the participants for all three intervention are presented in Table 16 below.

**Table 16. Age of participants**

Interventions	Age			Percentage of participants =< 25 years old	
	Mean	Minimum	Maximum		
Serious game	28	20.04	18	26	96.4
Paper-based game	34	20.91	18	47	94.1
Lecture	26	21.46	19	30	96.2

The majority of students (95%) participated in the study are digital natives which mean their age is 25 years or below.

### 5.8. Learning-Game Experience

A two-way analysis of variance between groups was conducted to find out the effect of previous learning game experience and interventions on the gain score. Table 17 contains descriptive information and analysis of the variance summary table.

**Table 17. Descriptive statistics of learning-game experience**

Dependent Variable: Gain Score

Intervention	Learning-Game Experience	Mean Gain		N
		Score	Std. Deviation	
Lecture	No	11.63	16.455	16
	Yes	1.09	16.379	10
	Total	7.57	16.922	26
Paper-based Game	No	5.32	26.768	22
	Yes	-4.67	28.166	12
	Total	1.79	27.274	34
Serious Game	No	12.33	22.871	15
	Yes	21.15	20.615	13
	Total	16.43	21.913	28
Total	No	9.21	22.788	53
	Yes	6.57	24.746	35
	Total	8.16	23.482	88

13 participants who had played learning games before, earned average gain scores of 21.15 ( $SD = 20.615$ ) in the serious game intervention group; 12 participants who had played learning games before in the paper-based game intervention group had an average gain score of negative 4.67 ( $SD = 28.166$ ). In all three intervention the 35 participants who had played learning games before earned an average gain score of 6.57 ( $SD = 24.746$ ) and the 53 participants who never played games for learning scored 9.21 ( $SD = 22.79$ ). The effect of interaction between previous learning game experience and intervention on the gain score, therefore, were not significant as shown in Table 18.

**Table 18. Interaction between learning game experience and pedagogies on the gain score**

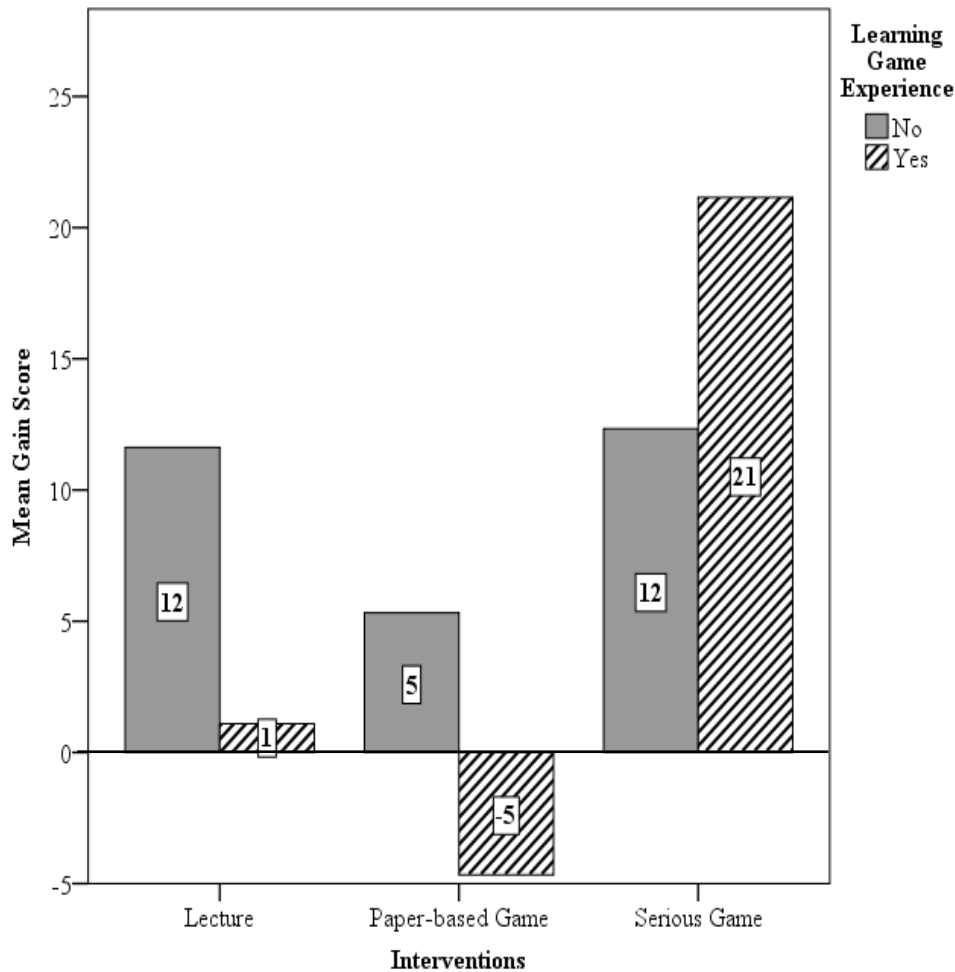
Dependent Variable: Gain Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5300.070 <sup>a</sup>	5	1060.014	2.037	.082
Intercept	5048.015	1	5048.015	9.700	.003
Intervention	4010.431	2	2005.215	3.853	.025
Previous Learning-Game Experience	314.742	1	314.742	.605	.439
Intervention * Previous Learning Game Experience	1685.292	2	842.646	1.619	.204
Error	42672.164	82	520.392		
Total	53828.830	88			
Corrected Total	47972.234	87			

a. R Squared = .110 (Adjusted R Squared = .056)

Figure 15 is a chart of the mean gain scores obtained by those who have the learning game-playing experience and who have no learning game-playing experience for the three intervention groups. The plot indicates that the participants with learning game-playing experience performed well in the serious game intervention group where as in the paper-based game intervention and in-class lecture interventions did not perform well, and the mean gain score of experienced learning game players was low, particularly in the case of the paper-based game intervention, it was worse. The hypothesis was that the

learning game-playing experience would have a positive impact gain score. With a P-value of 0.439, not less the designated alpha ( $\alpha$ ) value, it is safe to reject the hypothesis because the previous learning-game playing experience has no impact on gain scores.



**Figure 15. Chart of mean gain scores of three interventions based on learning game experience**

### 5.9. Relevant Field Experience

A two-way between-groups analysis of variance was carried out to find the effect of relevant field experience and interventions on the gain score. Table 19 shows the mean

gain scores of each participant in the experience category for different pedagogies.

**Table 19. Descriptive statistics of gain score and relevant field experience**

Interventions	Relevant Field Experience	Mean Gain Scores	Std. Deviation	N
Lecture	No experience	10.97	18.351	16
	Construction safety	2.55	11.085	8
	Construction	.50	27.577	2
	Total	7.57	16.922	26
Paper-based Game	No experience	5.90	29.227	21
	Construction safety	-6.80	24.397	5
	Construction	-3.63	24.272	8
	Total	1.79	27.274	34
Serious Game	No experience	18.61	20.858	18
	Construction safety	32.00	.	1
	Engineering design	11.00	.	1
	Construction	10.25	26.472	8
	Total	16.43	21.913	28
Total	No experience	11.54	24.000	55
	Construction safety	1.31	18.655	14
	Engineering design	11.00	.	1
	Construction	3.00	24.940	18
	Total	8.16	23.482	88

Fifty-five participants with no experience in all three intervention groups had average gain scores of 11.54 ( $SD = 24$ ); 18 participants with work experience in the serious game intervention group had an average gain score of 18.61 ( $SD = 20.89$ ).

**Table 20. Tests between-subjects effects: relevant work experience and interventions**

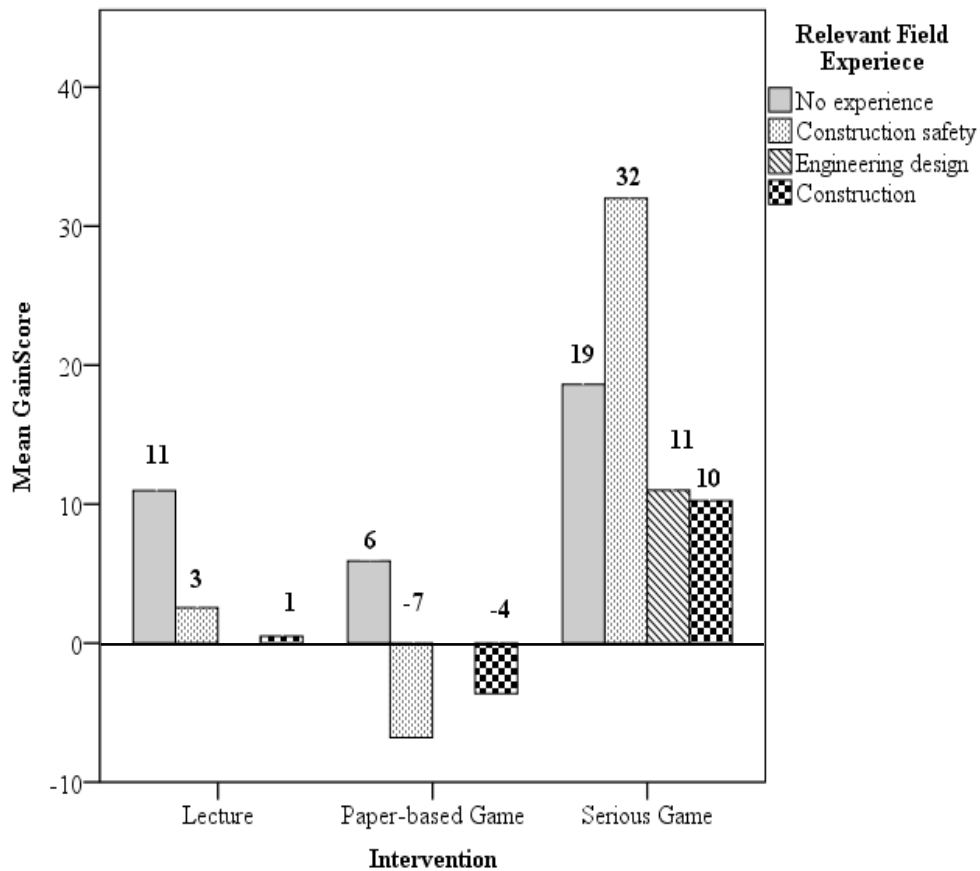
Dependent Variable: Gain Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5409.678 <sup>a</sup>	9	601.075	1.102	.372
Intercept	1000.438	1	1000.438	1.833	.180
Intervention	2760.635	2	1380.318	2.530	.086
Relevant Field Experience	987.681	3	329.227	.603	.615
Intervention * Relevant Field Experience	528.493	4	132.123	.242	.914
Error	42562.557	78	545.674		
Total	53828.830	88			
Corrected Total	47972.234	87			

a. R Squared = .113 (Adjusted R Squared = .010)

The interaction effect between relevant work experience and pedagogical interventions on the gain score was not a statistically significant,  $F(4, 78) = .242, p = .914$ . There was not a statistically significant main effect found for intervention  $F(2, 78) = 2.53, p = .086$ . The main effect of relevant experience,  $F(3, 78) = .603, p = .615$ , did not reach statistical significance.

Figure 16 shows a plot for the relevant work experience and the gain score of three interventions; it is evident that the students with construction safety experience got a higher score in the serious game group.



**Figure 16. Bar chart of relevant work experience on the gain score**

It is safe to accept the null hypothesis and claim that relevant work experience

does not significantly improve learning for any intervention.

### 5.10. Computer Use Frequency

The results of a two-way ANOVA show that there is not a statistically significant interaction between computer use frequency and intervention. Table 21 indicates that the students who use the computer more one 8 hours per week performed very well and the mean gain score was 17.06 ( $SD = 24.43$ ) and the students who use the computer for 6-8 hours per week their performance was also outstanding, but this category included only

**Table 21. Descriptive statistics of computer frequency**

Computer Use Frequency	Intervention	Mean Gain Score	Std. Deviation	Number of participants
More than 8 hrs. a wk.	Lecture	10.14	15.239	10
	Paper-based Game	1.96	29.487	25
	Serious Game	17.06	24.436	16
	Total	8.30	26.146	51
6-8 hrs. a wk.	Lecture	-4.60	15.059	7
	Paper-based Game	7.50	3.536	2
	Serious Game	31.67	29.143	3
	Total	6.48	23.034	12
4-6 hrs. a wk.	Lecture	11.90	22.029	4
	Paper-based Game	4.60	26.140	5
	Serious Game	10.29	14.198	7
	Total	8.91	19.219	16
2-4 hrs. a wk.	Lecture	12.07	17.321	3
	Paper-based Game	-13.00	19.799	2
	Total	2.04	20.893	5
0-2 hrs. a wk.	Lecture	21.95	.354	2
	Serious Game	10.00	7.071	2
	Total	15.98	8.019	4

three individuals. That is why the exceptional performance of those who play more than 6 hours is not statistically significant. In the table below, “N” indicates the number of students who use computer weekly for a particular amount of time. For

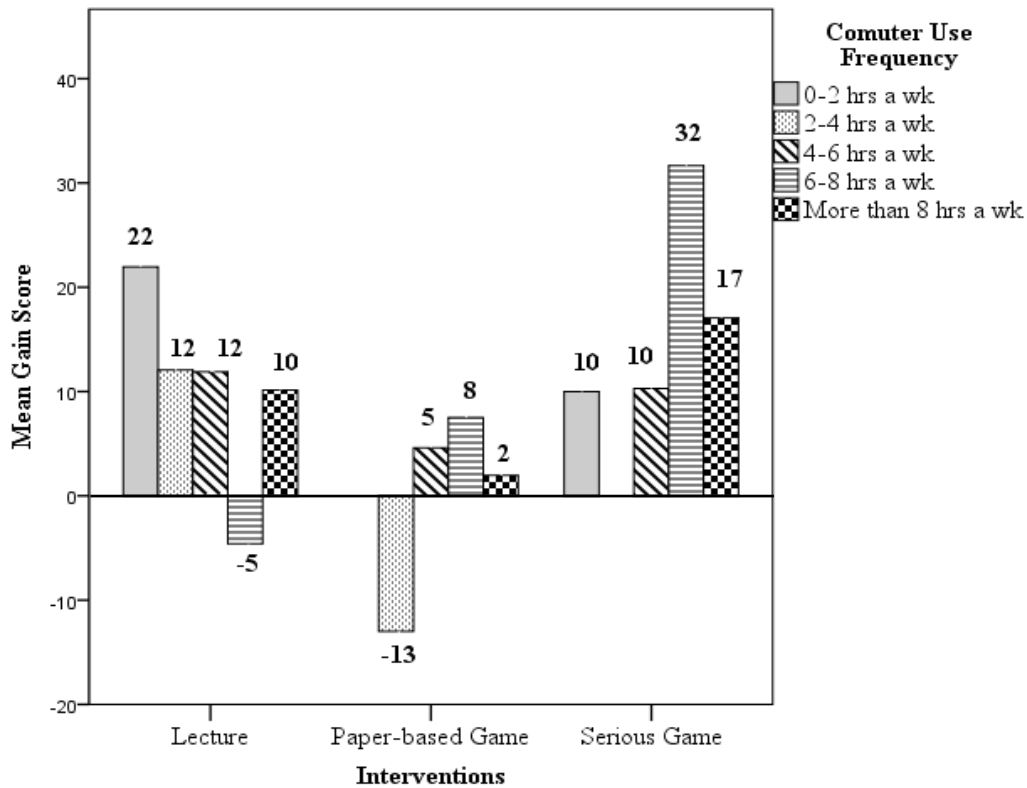
example, 51 students out of the total 88 participants use the computer more than 8 hours every week.

Table 22 shows that there was not a statistically significant effect of interaction between computer use frequency effect and interventions on gain scores,  $F(6, 75) = 0.909$   $p = 0.493$ , Partial  $\eta^2 = .068$ . Students who use computers more often had the highest gain score mean ( $M = 31.67$ ) for 6-8 computer usage per week.

**Table 22. Two-way ANOVA test between subjects**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6545.886 <sup>a</sup>	12	545.491	.988	.469
Intercept	3308.998	1	3308.998	5.991	.017
Computer Use Frequency	266.077	4	66.519	.120	.975
Intervention	1558.472	2	779.236	1.411	.250
Computer Use Frequency * Intervention	3013.086	6	502.181	.909	.493
Error	41426.348	75	552.351		
Total	53828.830	88			
Corrected Total	47972.234	87			

The results are not statistically significant, but the researcher wants to see the significance of the effect of the computer use frequency on learning performance in all three interventions. Figure 17 shows that the students who use more than 8 hours per week and 6-8 hours per week performed better than others.



**Figure 17. Bar chart of computer use frequency on the gain score**

Another interesting finding is that 22 students who reported computer use for the least amount of time (0-2 hours per week) scored higher in lecture intervention. It indicates that for non-computer users, lecture can be an effective method of learning.

### 5.11. Student Feedback

To understand the students' perspective, the author engaged a small group of ten students in discussing their experience of playing the paper-based game and serious game and unfortunately, no students from the in-class lecture group participated in the discussion. The comments of the participants can be divided into four groups. First, the three students who had never played computer games did not believe in their effectiveness for teaching. They said they consider these games "for kids" and they are



not interested in playing games. This indicates that not all students love to play games.

One common concern was the use of jargon such as safety hazards, controls, and formwork, etc. The second group of comments was related to the terminology used in the game. Students were not familiar with some of the terminologies about safety and construction. Therefore, those students who had difficulty in understanding a few basic terminologies did not enjoy playing the computer game, while others decided to search on Google to understand the meanings.

The third group of comments was regarding the game development process, and five students enjoyed playing the game. The fourth group of comments was regarding the paper-based game. Three students liked the colorful pictures, but they were not interested in reading “25 pages” to solve the “puzzle.”

### **5.12. Faculty Feedback**

Two instructors graciously helped the author in data collection from their students. One instructor mentioned that the consent form was given to students before the data collection that clearly mentioned that the activity was completely a voluntary exercise (as required by the Institutional Review Board) and students were free to stop their participation, anytime, that is why some students did not complete the tests or even left in the middle of the test. Overall, both instructors who were present during the intervention mentioned that the majority of the students liked the activity and asked follow-up questions next week in succeeding classes, especially regarding game development.

### 5.13. Summary

The results show that the SafeDesign game had a positive impact on learning; similarly, in-class lecture intervention also improved learning performance of students. However, the overall performance of the serious game group was higher than the other intervention groups. Only the paper-based game intervention did not work, and the students who used it earned the lowest score. The possible reason for a better performance in the lecture intervention group was that the lecture was delivered in construction safety class. 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 thus benefitted them in the tests. The paper-based game and the serious game groups were more comparable because the students had no previous safety course experience. In those two groups, the students in the serious game group performed better on their post-test results. In order to determine whether gender, 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 estimate the main effects and the interaction effects of these confounding variables. It was found that none of the factors had a statistically 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 impact was not statistically significant.

## CHAPTER 6: CONCLUSIONS

In literature, many anecdotal accounts from serious game players suggest that students like the gamification of the learning content. Researchers are continuously curious in finding out the pedagogical value of the application of serious games to teach a particular subject effectively.

This study tries to find the most effective pedagogical strategy out of three pedagogical approaches to teach the prevention through design concepts. In this chapter, the findings of the research and how it will impact the future of pedagogies are deliberated. The current study results are explained in comparing and contrasting with previous studies. The following sections of this chapter present the interpretation of learning scores of the serious game and two other pedagogies, limitations of the study, and suggestions for future research.

Scholars have identified that properly designed serious games are an effective instructional method for the Millennials. However, for teaching the PtD concepts, there is no specific study available. Therefore, this research tries to answer the questions of the pedagogical value of traditional versus non-traditional pedagogies and effect of other covariates on learning. The following were the six hypotheses stated in the study:

Hypothesis 1: An in-class lecture will positively impact learning.

Hypothesis 2: A paper-based game will positively impact learning.

Hypothesis 3: A serious game will positively impact learning.

Hypothesis 4: Gender will make an impact on learning.

Hypothesis 5: Relevant work experience will positively impact learning.

Hypothesis 6: Computer use frequency and learning game playing experience will positively impact the learning.

In the following section, each research hypothesis are examined to see whether the study results support the hypothesis.

When conducting a data independence check for this study, it was found that five participants were related to more than one intervention. The group of participants that used the serious game instructional method had three students who also participated in in-class lecture intervention. Similarly, the group of students who participated in in-class lecture intervention had two students who were also a member of the paper-based game group. To preserve the independence of the study, five participants were considered only once, when they participated for the first time.

### **6.1. Discussion of the Findings**

The SafeDesign game improved the student learning performance, as shown by the improvement in gain scores. Many studies (Andreu-Andre & Garci, 2011; de-Marcos et al., 2016; Dieleman & Huisingh, 2006; Kebritchi et al., 2010; Kwon & Lee, 2016; Papastergiou, 2009) have examined the impact of serious games on learning. The findings of this study are consistent with these previous study results.

On the other hand, in a research study Gale (2011) found that serious games have a motivational and engaging aspect for students. However, Gale's study did not find any benefit in improving the learning of students when compared against two interventions namely audio lecture and text reading. The current study results were not inconsistent with Gale's findings as it concludes that the serious game increased student learning.

The other two interventions, lecture, and paper-based game were also tested and found that student learning improved after lecture based intervention implemented. This finding is not in congruence with most of the popular literature (Bajak, 2014; Kaddoura, 2011; Liaghatdar, Abedi, Jafari, & Bahrami, 2004). When a third intervention the paper-based game was tested, the results of the study were shocking, as students using this pedagogy performed significantly worse on a posttest. The following sections discuss each pedagogy in detail.

### **6.1.1. SafeDesign Game**

The first hypothesis states that serious games will positively impact learning, has empirical support, which is inconsistent with an earlier scholarly findings (Andreu-Andre & Garci, 2011; Tang, Kelang, Lumpur, & Hanneghan, 2007; Universit et al., 2013). The results of this study show that serious games support learning. Serious games can engage learners because they enjoy experiencing success, and it keeps them involved. Since the SafeDesign game higher gain score as compared to the in-class lecture and the paper-based game, the researcher can assume that the serious game has benefitted students to an optimal level at least for this subject. One main contribution of the current study to body of knowledge is that this study compares the learning from the games and other pedagogies. In this study, the players have been presented twenty-five scenarios and asked to identify hazards and controls from a given list of options. The students also received feedback after selecting answers. The weights assigned to each attempt of the answer (first attempt= 10 points, second attempt = 7 points, third attempt = 5 points, and fourth attempt = 3 points) had motivating effect for students and probably they made

serious effort to get the highest points.

### **6.1.2. Paper-based Game**

The second hypothesis is that using a paper-based game will positively augment learning; the findings were not statistically significant. In other words, the participants using this pedagogical intervention performed significantly worse when compared to the other two interventions. Hence, this hypothesis could not find the support. When compared to the in-class lecture, or the serious game, the mean gain scores were very low. The author suspects that low mean gain scores were due to the low level of the students' interest in reading and understanding the paper-based game scenarios.

Despite the large number of studies in literature support that using illustration and graphics in teaching improve learning (Stokes, 2002), the researcher did not find statistical support for the same in this study. For the paper-based game, the scenarios were developed using illustrations, very similar to the 3D graphics used in the serious game. Perhaps these illustrations and the storyline to explain the scenes in the paper-based game were quite distracting for the students and it did not help the students' learning. Researchers, for example, Weidenmann pointed out that there is a good reason to doubt the benefits of pictures in the educational text (Weidenmann, 1989). He said learners would often consider illustrations superficially or inadequately failing in achieving any contribution to learning. Historically, the illustrations had been used to convey knowledge from generation to generation. Using images to create scenarios is one of the main ingredients of a paper-based game. Scenarios are meant to convey an unsafe workplace situation that can potentially hurt anyone present on a site such as workers or

visitors as shown in Appendix G. The students were given solved questions and options to select from the list of hazards and controls, see Appendices H and I. From the results of the study, it can be concluded that illustrations with the written description of scenarios were perhaps taken as a distraction, as it diverts attention from learning, and in its place creates the frustration of not reading and observing the scenarios carefully. In this intervention, the total time to work on the paper-based game, and take the posttest, was only 70 minutes. In this short period, the new approach of using illustrations for scenarios perhaps distracted the students' focus from the subject. This activity might have resulted in interruption or cognitive overload. The students were exposed to the safety content for the first time, so the terminologies and situations presented to them were possibly overwhelming.

### **6.1.3. In-class Lecture Pedagogy**

In the current study, the third hypothesis, an in-class lecture will positively impact learning, has support of experimental results, but it is inconsistent with the previous studies about the effectiveness of lecture-based learning (Antepohl & Herzig, 1999; Bajak, 2014; Hwang & Kim, 2006; Kaddoura, 2011; Liaghatdar et al., 2004). These study results suggest that in-class lecture leads to learning. The fact that the class where the intervention was implemented was construction safety class, therefore this may have helped them receiving a high score of learning performance. The students in this group were taught the terminologies and basic principles of safety, which are also required to understand the PtD concepts. The lecture-based learning has a statistically significant improvement in the gain score, but the impact of other variables such as gender, previous

knowledge, relevant work experience and game-playing frequency did not prove to be linked with this intervention.

In the past, the effectiveness of lectures to teach PtD has been questioned, but many researchers have suggested that designing a lecture-based learning activity on the principles of adult learning keeping in mind the relevance of the topic with the students needs, incorporating interactive teaching, developing connections with the student's previous knowledge and work experience may help to increase learning (Palis & Quiros, 2014). In the current study, the researcher delivered only one lecture of about 45 minutes and tried to follow all possible adult learning principles such as linking the lecture content with the student's previous knowledge and experience. Out of the four principles, the lecture was based on two principles that are relevant with student's previous knowledge and work experience experience. Even with these two principles, the results are statistically significant and in agreement with Palis and Quiros (2014) interpretations of using adult learning principles for better learning. One of the contributions of the current study is the empirical evidence of the effectiveness of the lecture-based pedagogy when delivered considering adult education principles. It shows that students, who are in a construction safety class and should be taught an additional topic of prevention through design.

#### **6.1.4. Gender**

As discussed in Chapter 3, previously, literature on games showed that there was an inconsistency between male and female students' interest to using computer games. Hartmann and Klimmt (2006) found in a survey that females are less interested in video



games than males, and when they choose to play, they frequently prefer dissimilar computer games. However, recent studies on gender and games present different views. For example, in a study Klisch, Miller, Wang and Epstein (2012) and Chang, Evans, Kim, Deater-Deckard, and Norton (2014) found that female learners scored higher than males in term of learning performance score and engagement. In addition, according to the Entertainment Software Association (ESA), the number of female video game players has escalated also. According to ESA, women are 42 percent of all game players. Interestingly, 41 percent of total game players are adult females, whereas 17 percent of video gaming players are boys of age 17 or younger (The Entertainment Software Association, 2016). Again, in several studies, no significant difference was reported between male and female student's learning performance after using serious games (Annetta, Mangrum, Holmes, Collazo, & Cheng, 2009; Ke & Grabowski, 2007; Papastergiou, 2009). Several studies provide evidential support for a difference in learning performance between male and female students. While several other studies found no difference in learning performance based on gender. The current study also found no statistically significant difference between male and female learning performance, but female students had a better gain score as compared to male participants.

#### **6.1.5. Relevant Work Experience**

This study did not find a statistically significant relationship with previous relevant work experience. Overall, a student who possessed professional experience in the field of safety performed better, though not statistically significant.

### **6.1.6. Computer Use Frequency**

The students who use the computer more often for work and a game like to play serious games. Whereas students with low computer use mostly liked lecture based teaching methods.

### **6.1.7. Experience of Learning Games**

The student who had learning game experience performed better in the serious game activity, but in other two interventions, their performance was deficient.

### **6.1.8. Game Development Experience**

Generally, the development of a serious game combines the skills of numerous disciplines, from subject matter experts on the topic being taught; to story developers, game designers, and software developers; to instructional designers, educational assessment scientists, and others (Strzalkowski & Symborski, 2017). However, in order to conduct a prototype testing in a formal education setting, the chances of availability of all the resources mentioned above are rare. Therefore, a researcher or instructor would require knowing the process of game development to use the promising technology of the serious game. The author has listed lessons learned to provide guidelines and take away points to assist educators in their future efforts to create effective serious games.

### **6.1.9. Limitations of the Study**

There are many inherent limitations of quasi-experimental research. Some of these constraints are discussed in this section.

1. This study was implemented with a relatively small sample size of three classes (88 valid participants); therefore, the results of this research cannot be generalized. This exercise of measuring pedagogical value of interventions to teach prevention through design topics is a pilot study.
2. Since the time distance between the pretests and posttests was approximately two weeks. It is hard to infer whether the serious game would help long-term knowledge retention.
3. There are numerous aspects of a serious game such as better audio and visual effects, and 3D navigation capabilities which are required a game to be commercially successful. Therefore, a professional game designer and a team of developers could make a high-quality game that most of us are used to seeing. This study focuses only on testing the proof of concept. Therefore the researcher himself designed content development, coding, graphic design, audio design, etc. The quality is not at par with commercially available games.
4. There are some aspects of designing an effective paper-based game. The graphic design quality, storytelling, game playing can have a significant impact on learning. In this study, the researcher designed the paper-based game based on the serious game scenarios, and probably this had some weakness, which influenced the results of the study.
5. In order to deliver an effective lecture, teaching experience plays a vital role. The duration of the lectures was only 45 minutes, and the researcher had not interacted with students before this activity which might have a negative effect on learning and teaching. The researcher did, however, has five years of experience in the

classroom instruction in the past.

## **6.2. Recommendations for Future Research**

Use of serious games for construction safety education is a rather new field of research. There is an enormous opportunity for further exploration in this field. Keeping in view the current work, the following are recommendations for future studies:

1. In order to improve the effectiveness of a paper-based game, cognitive load theory should be considered (Paas & Sweller, 2014). According to the theory, a learner can only process a certain amount of information due to one's short-term memory capacity. Therefore, it is suggested to re-design a paper-based material and implement the invention to evaluate its effectiveness.
2. An application of the in-class lecture in a non-safety class, including with civil engineering students, might help to inform whether a lecture-based teaching method contributes to improving prevention through design learning. Another possible study could be about measuring the effectiveness of these all three-pedagogical interventions in civil engineering discipline, and any other engineering disciplines such as chemical, electrical, and mechanical engineering.
3. Detailed research is recommended to understand the effect of serious games features such as audio and 3D graphics that will probably help to develop exciting learning games.
4. Further research is also required to determine whether game and lecture interventions contribute towards long-term retention of knowledge.

### 6.3. Contributions

This research provides new perspectives for the development and use of serious games for health and safety education. For example, the development and investigation of serious games have been described at length previously in the dissertation since understanding the serious game design process gives crucial insights into the requirements of an effective serious game.

As of now, no study offers empirical evidence to suggest the use of serious games to teach prevention through design principles to university students at the undergraduate level. This research adds to the existing knowledge base on game-based learning for construction management and construction engineering students, which is still fairly a new field of study.

In essence, the main knowledge contribution of this dissertation stems from the development of the serious game and its implementation for teaching the concept of prevention through design.

- *Serious games and lecture-based instruction are effective strategies for teaching the prevention through design concepts.* This study highlights the effectiveness of these two approaches. In case of the lecture, when the topics of PtD are included along with the regular safety topics, students learn these concepts effectively. The game-based teaching method is also helpful for students to learn the PtD concepts. The serious game proved better than any other methods of teaching in this study.
- *Development of the first serious game for PtD education from a pedagogical perspective.* Few serious games are available commercially in the field of

construction health and safety training, and none of them is on prevention through design education of university students. The researcher developed and implemented the first ever game to teach the prevention through design concepts.

- *First study for evaluating the usefulness of serious games for PtD education.*

The researcher compared the learning from the SafeDesign game with the alternative teaching approaches of the in-class lecture and the paper-based game to determine the pedagogical value of the serious game in the field of teaching the prevention through design concepts to construction management students.

- *Summary of research on game development.* Through a summary of the literature, previous research and commonly used approaches to design serious games is described.
- *Compilation of lesson learned from game development.* The researcher compiled the lessons learned during the development of the game, which can help instructors to develop a low-cost serious game. For example, lessons learned to deliver information on how a teacher will develop a simple 3D game, how much the game and hardware will cost, and how student performances will be evaluated.

### **1.1. Summary**

Well-designed serious games have the potential to turn learning into a fun challenge through the right blend of instructive and entertaining elements. Also, lecture-based teaching and learning can help students when the lecture is based on the adult education principles such as it meets a student's needs, interactive, and considers

student's background knowledge and experience. Among the various factors or confounding variables studied, the author did not find any of them essential elements of learning, which positively augment learning. For example, gender, relevant fieldwork experience, and learning game playing experience did not seem to help toward learning for this relatively small sample. Among interventions, the illustrations on the paper-based game distracted students from the educational features of the game.

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 research may be able to focus on what features of a game are necessary for a positive impact on learning. The effect of features such as better graphics, audio, and 3D navigation capabilities should also be studied.

We should not 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.

A collaboration between game designers and educationists can result in the development of effective serious games possessing the right kind of entertainment and pedagogical features.

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APPENDIX A

PRETEST FOR IN-CLASS LECTURE INTERVENTION

## GENERAL INFORMATION

**Question 1.** Please indicate your age.

\_\_\_\_\_ Years

**Question 2.** Please indicate your gender.

- a) Female
- b) Male
- c) Prefer not to answer

**Question 3.** Indicate your major as of now.

*Please circle only one option.*

- a) Construction Engineering
- b) Construction Management
- c) Civil Engineering
- d) Other\_\_\_\_\_

**Question 4.** Indicate your academic standing.

*Please circle only one option.*

- a) Freshman
- b) Sophomore
- c) Junior
- d) Senior

**Question 5.** In what year do you anticipate graduating?

20\_\_\_\_\_.

**Question 6.** Indicate your experience related to each of the following fields

*Please check all that apply.*

**Construction Safety****Engineering Design****Construction**

Internship

Internship

Internship

Professional work

Professional work

Professional work

Not Applicable

Not Applicable

Not Applicable

**Question 7.** What type of construction safety course(s) **other than CON 271** have you started taking or completed?

*Please check all that apply.*

	<b>In progress</b>	<b>Completed</b>
a) OSHA training (Please indicate training title such as OSHA 510, 30-Hr, etc.)	<input type="checkbox"/>	<input type="checkbox"/>
_____		
b) Other safety training	<input type="checkbox"/>	<input type="checkbox"/>
_____		
c)	None	None

**TECHNICAL BACKGROUND**

**Question 8.** I use a computer for coursework.

*Please circle only one option.*

- a) More than 8 hours a week
- b) 6-8 hours a week
- c) 4-6 hours a week
- d) 2-4 hours a week
- e) 0-2 hours a week

f) Other \_\_\_\_\_

**Question 9.** I typically play video games.

*Please circle only one option.*

- a) More than 8 hours a week
- b) 6-8 hours a week
- c) 4-6 hours a week
- d) 2-4 hours a week
- e) 0-2 hours a week
- f) I do not play video games at all.

**Question 10.** For how long you have been playing video games at the frequency you reported in Question 9?

*Please circle only one option.*

- a) 6 years or more years
- b) 5 years
- c) 4 years
- d) 3 years
- e) 2 years
- f) 1 year
- g) Less than one year

**Question 11.** How much enjoyment do you get from playing video games?

*Please circle only one option.*

- a) A great deal
- b) A lot

- c) A moderate amount
- d) A little
- e) Not at all

**Question 12.** Have you ever used computer gaming for learning? If so, what are those games?

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**Question 13.** If you have used computer gaming for learning before, please rate your experience.

*Please circle only one option.*

- a) No value
- b) Limited value
- c) Average value
- d) Much value
- e) Extreme value

**EXPECTATION LEVEL** (*Please circle only one option.*)

**Question 14.** Do you expect that the lecture will be an effective tool for teaching Safety by Design (also called Prevention through Design)?

Not	A Little	A moderate	A lot	A great	No
at all		amount		deal	opinion

**Question 15.** Do you expect that you will enjoy learning safety by design using lecture-based teaching method?  
*(Do not consider how you learn, just how much enjoy being in the class)*

Not	A Little	A moderate	A lot	A great	No
-----	----------	------------	-------	---------	----

at all                      amount                      deal                      opinion

**Question 16.** Do you expect that you will be able to apply what you learn in the real world?

Not              A Little              A moderate              A lot              A great              No

at all                      amount                      deal                      opinion

**Question 17.** Do you expect that the lecture will cover topics that important to learn?

Not              A Little              A moderate              A lot              A great              No

at all                      amount                      deal                      opinion

### **CONTENT UNDERSTANDING**

**Question 18.** What is an example of construction safety problems in the civil and construction discipline?

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**Question 19.** Are there any building design strategies that add/improve construction and operation safety of a project?

*Please mark only one option.*

- a) Yes\_\_\_\_\_
- b) No\_\_\_\_\_
- c) I do not know\_\_\_\_\_

**Question 20.** Do you think consideration of worker safety in the design development is different from safety management during the construction?

*Please mark only one option.*

- a) Yes\_\_\_\_\_



- b) No\_\_\_\_\_
- c) I do not know\_\_\_\_\_

If your answer is yes, could you explain the differences?

---

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**Question 21.** What general aspects of building construction and operation related to safety can be affected by including safety in design?

*Multiple Select (Circle all that apply):*

- a) Visitors' safety
- b) Workers' behavior
- c) Contractors' commitment to safety
- d) Worker's safety
- e) Utilization of safe materials

**Question 22.** What measures can be taken to control safety hazards through a proper site layout design on a construction project?

*Multiple Select (Circle all that apply)*

- a) Safe material storage
- b) Traffic control on site
- c) Visitor control
- d) Potentially hazardous material storage
- e) Fall from height
- f) Crane safety
- g) All above

h. I do not know.

**Question 23.** To the best of your understanding, define Prevention through Design or Safety through Design in one or two sentences.

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**Question 24.** What are the dangers of trenching and excavation operation very close to the foundations of an existing building and how to control them?

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**Question 25.** What are the dangers of working very close to powerlines and how to control them?

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**Question 26.** What are the dangers of working extensive hours on jobsite and how to control them?

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**Question 27.** What are safety hazards for workers while constructing the supper-structure portion of a building and how will you control them? *For example, safety hazards related to working at height.*

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**Question 28.** What are safety hazards for workers in operating & maintaining buildings

and how will you control them? *For example, safety hazards during changing a light bulb at height.*

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**Thank you for your time!**

## APPENDIX B

### POSTTEST FOR THE IN-CLASS LECTURE INTERVENTION

## GENERAL INFORMATION

**Question 1.** What is your experimental ID number?

\_\_\_\_\_

## ENGAGEMENT LEVEL

**Question 2.** Do you think that the lecture was an effective tool for teaching Safety by Design (also called Prevention through Design)?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 3.** Have you enjoyed in-class lecture today?

*(Do not consider how you learn, just how much enjoy being in the class)*

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 4.** How important do you feel it was to pay attention to in-class lecture was?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 5.** Do you think that you will be able to apply what you learn in the real world?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 6.** How successful do you believe you were in grasping the concept of Prevention through Design?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

## CONTENT UNDERSTANDING

**Question 7.** In your opinion, what are the potential hazards for workers and general public in construction?

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**Question 8.** In your opinion, is it possible to reduce or eliminate safety hazards through design approaches?

*Please select only one option.*

- a) Yes\_\_\_\_\_
- b) No\_\_\_\_\_
- c) I do not know\_\_\_\_\_

**Question 9.** Do you think consideration of worker safety in the design process is different from safety management during the construction process?

- a) Yes\_\_\_\_\_
- b) No\_\_\_\_\_
- c) I do not know\_\_\_\_\_

If your answer is yes, could you explain how is it different?

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**Question 10.** To the best of your understanding, define Prevention through Design or Safety by Design in one or two sentences.

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**Question 11.** Are there any drawbacks when engineers/construction professionals do not consider safety in the design process of construction projects? If so, list an example or

two.

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**Question 12.** Multiple Select (*Please circle all that apply*)

Which safety hazards will you be able to affect as a construction manager/engineer?

- a) Workers' unsafe behavior
- b) Management's commitment to safety
- c) Fall from height
- d) Struck by falling or moving objects
- e) Caught in or between two surfaces
- f) Exposure to hazardous chemicals
- g) Trips and Slips
- h) All above
- i) I do not know.

**Question 13.** Multiple Select (*Please circle all that apply*)

Through better **construction site layout design**, what aspects of safety will you be able to affect? *Please select the hazards and their mitigation you learned in this class today.*

- a) Safe material storage
- b) Traffic control on site
- c) Visitor control
- d) Potentially hazardous material storage
- e) Fall from height
- f) Crane safety

g) All above

h) I do not know.

**Question 14.** What are the dangers of working very close to powerlines and how to control them?

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**Question 15.** What are the dangers of working extensive hours on jobsite and how to control them?

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**Question 16.** Which aspects of safety related to **foundation excavation of building** will you be able to affect? *Please mention the hazards and their mitigation you learnt in this class today.*

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**Question 17.** As a construction manager/engineer, which aspects of safety related to construction of superstructure will you be able to affect? *(The superstructure of a building is the part that is entirely above its foundation or basement)*  
*Please mention the hazards and their mitigation you learnt in this class today.*

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**Question 18.** As a construction manager/engineer, which aspects of safety related to **operation & maintenance a building** will you be able to affect?



*Please mention the hazards and their mitigation you learnt in the class today.*

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**Thank you for your time!**

## APPENDIX C

### PRETEST FOR THE PAPER-BASED GAME INTERVENTION

**GENERAL INFORMATION**

**Question 1.** Please indicate your age.

\_\_\_\_\_ Years

**Question 2.** Please indicate your gender.

- a) Female
- b) Male
- c) Prefer not to answer

**Question 3.** Indicate your major as of now.

- a) Construction Engineering
- b) Construction Management
- c) Civil Engineering

**Question 4.** Indicate your academic standing and anticipated year of graduation.

- a) Freshman
- b) Sophomore
- c) Junior
- d) d. Senior
- e) e. Year 20\_\_\_\_\_

**WORK EXPERIENCE AND SAFETY EDUCATION**

**Question 5.** Indicate your experience related to different fields.

---

<u>Construction Safety</u>	<u>Engineering Design</u>	<u>Construction</u>
a) Internship	a) Internship	a) Internship

---

b) Professional work

b) Professional work

b) Professional work

c) Not applicable

c) Not applicable

c) Not applicable

**Question 6.** What type of course(s) have you started taking or completed?

*Please check all that apply.*

	<b>In progress</b>	<b>Completed</b>
a) Construction Safety – CON 271	<input type="checkbox"/>	<input type="checkbox"/>
b) OSHA training (Please indicate the title such as OSHA 510, 30-Hr, etc.)_____	<input type="checkbox"/>	<input type="checkbox"/>
c) Other safety training	<input type="checkbox"/>	<input type="checkbox"/>

**TECHNICAL BACKGROUND**

**Question 7.** I use a computer for coursework.

- a) More than 8 hours a week
- b) 6-8 hours a week
- c) 4-6 hours a week
- d) 2-4 hours a week
- e) 0-2 hours a week
- f) Other \_\_\_\_\_

**Question 8.** I play video games regularly.

- a) More than 8 hours a week
- b) 6-8 hours a week
- c) 4-6 hours a week

- d) 2-4 hours a week
- e) 0-2 hours a week
- f) I do not play video games at all.

**Question 9.** I have been playing video games for the past:

- a) years or more years
- b) years
- c) years
- d) years
- e) years
- f) 1 year
- g) Less than one year

**Question 10.** How much enjoyment do you get from playing video games?

- a) A great deal
- b) A lot
- c) A moderate amount
- d) A little
- e) Not at all

**Question 11.** Have you ever used computer gaming for learning before? If so, what?

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**Question 12.** If you have used computer gaming for learning before, please rate your experience.

- a) No value

- b) Limited value
- c) Average value
- d) Much value
- e) Extreme value

## MOTIVATION LEVEL

*Please circle only one option.*

**Question 13.** Are you looking forward to this hazard identification activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 14.** How useful do you believe this activity will be?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 15.** How important do you feel it will be to do well on this exercise?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 16.** How pleasant do you expect this activity to be?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 17.** How much effort do you plan to put into this activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 18.** How successful do you believe you will be in completing this activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

at all

amount

## **CONTENT UNDERSTANDING**

**Question 19.** What is an example of construction safety problems in the civil and construction discipline?

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---

**Question 20.** Are there any building design strategies that add/improve construction and operation safety of a project?

*Select only one option.*

- a) Yes
- b) No
- c) I do not know

**Question 21.** What general aspects of building construction and operation related to safety could be affected by including safety in design?

*Multiple Select (Circle all that apply):*

- a) Visitors' safety
- b) Workers' behavior
- c) Contractors' commitment to safety
- d) Worker's safety
- e) Utilization of safe materials
- f) All above
- g) I do not know.

**Question 22.** To the best of your understanding, define Prevention through Design or

Safety through Design in one or two sentences.

---

---

**Question 23.** What are the dangers of trenching and excavation operation very close to foundations of an existing building and how to control them?

---

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**Question 24.** What are the dangers of working very close to powerlines and how to control them?

---

---

**Question 25.** What are the dangers of working extensive hours on jobsite and how to control them?

---

---

**Question 26.** Which hazards (which categories) would you potentially be able to affect through the Prevention through Design game?

*Multiple Select (Circle all that apply):*

- a) Hazards related to workers' behavior
- b) Contractors' commitment to safety
- c) Falls
- d) Struck by falling or moving objects
- e) Caught in or between two surfaces



- f) Exposure to chemicals
- g) Trips, Slips, and Falls
- h) All above
- i) I do not know.

**Question 27.** What measures can be taken to control safety hazards through a proper site layout design on a construction project?

*Multiple Select (Circle all that apply)*

- a) Safe material storage
- b) Traffic control on site
- c) Visitor control
- d) Potentially hazardous material storage
- e) Fall from height
- f) Crane safety
- g) All above
- h) I do not know.

**Question 28.** What are the dangers of trenching and excavation operation and how to control them through integration of safety in the design of excavation operations?

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**Question 29.** What are safety hazards for workers while constructing the super-structure portion of a building and how will you control them? *For example, safety hazards related working at height.*

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---

**Question 30.** What are safety hazards for workers in operating & maintaining the building and how will you control them? *For example, safety hazards during changing a light bulb at height.*

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**Thank you for your time!**

## APPENDIX D

### POSTTEST FOR THE PAPER-BASED GAME INTERVENTION

**GENERAL INFORMATION**

**Question 1.**What is your experimental ID number?

\_\_\_\_\_

**ENGAGEMENT LEVEL**

*Please circle only one option.*

**Question 2.** Have you enjoyed this hazard identification activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 3.** How useful do you believe this activity was?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 4.** How important do you feel it was to do well on this exercise?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 5.** How pleasant do you think this activity was?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 6.** How much effort did put into this activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 7.** How successful do you believe you were in completing this activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

## CONTENT UNDERSTANDING

**Question 8.** What is an example of construction safety problems in the civil and construction discipline?

---

---

**Question 9.** Are there any building design strategies that add/improve construction and operation safety of a project?

*Select only one option.*

- a) Yes
- b) No
- c) I do not know

**Question 10.** What topics of Safety in Design have you learned through the activity today?

*Multiple Select (Circle all that apply)*

- a) Visitors' safety
- b) Workers' unsafe behavior
- c) Workers' behavior
- d) Management's commitment to safety
- e) Contractors' commitment to safety
- f) Fall from height
- g) Worker's safety
- h) Struck by falling or moving objects
- i) Utilization of safe materials
- j) Caught in or between two surfaces
- k) All above

**Question 11.** To the best of your understanding, define Prevention through Design or

Safety through Design in one or two sentences.

---

---

**Question 12.** What are the dangers of trenching and excavation operation very close to foundations of an existing building and how to control them?

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---

**Question 13.** What are the dangers of working very close to powerlines and how to control them?

---

---

**Question 14.** What are the dangers of working extensive hours on jobsite and how to control them?

---

---

**Question 15.** What measures can be taken to control safety hazards through a proper site layout design on a construction project?

*Multiple Select (Circle all that apply)*

- a) Safe material storage
- b) Traffic control on site
- c) Visitor control
- d) Potentially hazardous material storage
- e) Fall from height

- f) Crane safety
- g) All above
- h) I do not know.

**Question 16.** What are the dangers of trenching and excavation operation and how to control them through integration of safety in the design of excavation operations?

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**Question 17.** What are safety hazards for workers while constructing the supper-structure portion of a building and how will you control them? *(The superstructure of a building is the part that is entirely above its foundation or basement)*

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**Question 18.** What are safety hazards for workers in operating & maintaining the building and how will you control them? *For example, safety hazards during changing a light bulb at height.*

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**Thank You!**

## APPENDIX E

### PRETEST FOR THE SAFEDESIGN GAME INTERVENTION



## Pretest- SafeDesign Game

### GENERAL INFORMATION

**Question 1.** Please indicate your age.

\_\_\_\_\_ years

**Question 2.** Please indicate your gender.

- a) Female
- b) Male
- c) Prefer not to answer

**Question 3.** Indicate your major as of now.

- a) Construction Engineering
- b) Construction Management
- c) Civil Engineering

**Question 4.** Indicate your academic standing and anticipated year of graduation.

- a) Freshman
- b) Sophomore
- c) Junior
- d) Senior
- e) Year 20\_\_\_\_\_

### WORK EXPERIENCE AND SAFETY EDUCATION

**Question 5.** Indicate your experience related to different fields.

---

Construction Safety	Engineering Design	Construction
a) Internship	a) Internship	a) Internship

---

- b) Professional work                      b) Professional work                      b) Professional work
- c) Not applicable                              c) Not applicable                              c) Not applicable

**Question 6.** What type of course(s) have you started taking or completed?

*Please check all that apply.*

	<b>In progress</b>	<b>Completed</b>
a) Construction Safety – CON 271	<input type="checkbox"/>	<input type="checkbox"/>
b) OSHA training (Please indicate the title such as OSHA 510, 30-Hr, etc.)_____	<input type="checkbox"/>	<input type="checkbox"/>
c) Other safety training	<input type="checkbox"/>	<input type="checkbox"/>

---

**TECHNICAL BACKGROUND**

Question 7. I use a computer for coursework.

- a) More than 8 hours a week
- b) 6-8 hours a week
- c) 4-6 hours a week
- d) 2-4 hours a week
- e) 0-2 hours a week
- f) Other \_\_\_\_\_

**Question 8.** I play video games regularly.

- a) More than 8 hours a week
- b) 6-8 hours a week
- c) 4-6 hours a week

- d) 2-4 hours a week
- e) 0-2 hours a week
- f) I do not play video games at all.

**Question 9.** I have been playing video games for the past:

- a) years or more years
- b) years
- c) years
- d) years
- e) years
- f) 1 year
- g) Less than one year

**Question 10.** How much enjoyment do you get from playing video games?

- a) A great deal
- b) A lot
- c) A moderate amount
- d) A little
- e) Not at all

**Question 11.** Have you ever used computer gaming for learning before? If so, what?

---

---

**Question 12.** If you have used computer gaming for learning before, please rate your experience.

- a) No value

- b) Limited value
- c) Average value
- d) Much value
- e) Extreme value

**MOTIVATION LEVEL**

*Please circle only one option.*

**Question 13.** Are you looking forward to this hazard identification activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 14.** How useful do you believe this activity will be?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 15.** How important do you feel it will be to do well on this exercise?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 16.** How pleasant do you expect this activity to be?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 17.** How much effort do you plan to put into this activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

**Question 18.** How successful do you believe you will be in completing this activity?

Not at all      A Little      A moderate amount      A lot      A great deal      No opinion

at all amount

## CONTENT UNDERSTANDING

**Question 19.** What is an example of construction safety problems in the civil and construction discipline?

---

---

**Question 20.** Are there any building design strategies that add/improve construction and operation safety of a project?

*Select only one option.*

- a) Yes
- b) No
- c) I do not know

**Question 21.** What general aspects of building construction and operation related to safety could be affected by including safety in design?

*Multiple Select (Circle all that apply):*

- a) Visitors' safety
- b) Workers' behavior
- c) Contractors' commitment to safety
- d) Worker's safety
- e) Utilization of safe materials
- f) All above
- g) I do not know.

**Question 22.** To the best of your understanding, define Prevention through Design or

Safety through Design in one or two sentences.

---

---

**Question 23.** What are the dangers of trenching and excavation operation very close to foundations of an existing building and how to control them?

---

---

**Question 24.** What are the dangers of working very close to powerlines and how to control them?

---

---

**Question 25.** What are the dangers of working extensive hours on jobsite and how to control them?

---

---

**Question 26.** Which hazards (which categories) would you potentially be able to affect through the Prevention through Design game?

*Multiple Select (Circle all that apply):*

- a) Hazards related to workers' behavior
- b) Contractors' commitment to safety
- c) Falls
- d) Struck by falling or moving objects
- e) Caught in or between two surfaces

- f) Exposure to chemicals
- g) Trips, Slips, and Falls
- h) All above
- i) I do not know.

**Question 27.** What measures can be taken to control safety hazards through a proper site layout design on a construction project?

*Multiple Select (Circle all that apply)*

- a) Safe material storage
- b) Traffic control on site
- c) Visitor control
- d) Potentially hazardous material storage
- e) Fall from height
- f) Crane safety
- g) All above
- h) I do not know.

**Question 28.** What are the dangers of trenching and excavation operation and how to control them through integration of safety in the design of excavation operations?

---

---

**Question 29.** What are safety hazards for workers while constructing the super-structure portion of a building and how will you control them? *For example, safety hazards related working at height.*

---

---

**Question 30.** What are safety hazards for workers in operating & maintaining the building and how will you control them? *For example, safety hazards during changing a light bulb at height.*

---

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## APPENDIX F

### POSTTEST FOR THE SAFEDESIGN GAME INTERVENTION

## Posttest-Safedesign Game

### GENERAL INFORMATION

**Question 1.** What is your experimental ID number? \_\_\_\_\_

Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2. I lost track of time.	1	2	3	4	5
3. Things seemed to happen automatically.	1	2	3	4	5
4. I felt different.	1	2	3	4	5
5. I felt scared.	1	2	3	4	5
6. The game felt real.	1	2	3	4	5
7. If someone talked to me, I didn't hear them.	1	2	3	4	5
8. I got wound up.	1	2	3	4	5
9. Time seemed to kind of standstill or stop.	1	2	3	4	5
10. I felt spaced out.	1	2	3	4	5
11. I didn't answer when someone talked to me.	1	2	3	4	5
12. I couldn't tell if I was getting tired.	1	2	3	4	5
13. Playing seemed automatic.	1	2	3	4	5
14. My thoughts were going fast.	1	2	3	4	5

15. I lost track of where I was.	1	2	3	4	5
16. I played without thinking about how to play.	1	2	3	4	5
17. Playing made me feel calm.	1	2	3	4	5
18. I played longer than I meant to	1	2	3	4	5
19. I really got into the game.	1	2	3	4	5
20. I felt like I just couldn't stop playing	1	2	3	4	5

---

**Question 1.a.** Scenes Completed: -----

**Question 1.b.** Total Score: -----

**GAME ENGAGEMENT**

**CONTENT UNDERSTANDING**

**Question 21.** What are the hazards for workers and general public in construction?

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**Question 22.** In your opinion, is it possible to reduce or eliminate safety hazards through design approaches?

*Please select only one option.*

- a) Yes\_\_\_\_\_
- b) No\_\_\_\_\_
- c) I do not know\_\_\_\_\_

**Question 23.** Do you think consideration of worker safety in the design development is

different from safety management during the construction?

- a) Yes\_\_\_\_\_
- b) No\_\_\_\_\_
- c) I do not know\_\_\_\_\_

If your answer is yes, could you explain the differences?

---

---

**Question 24.** Multiple Select (Please circle all that apply)

Which safety hazards were you able to affect in SafeDesign game?

- a) Workers' unsafe behavior
- b) Management's commitment to safety
- c) Fall
- d) Struck by falling or moving objects
- e) Caught in or between two surfaces
- f) Exposure to hazardous chemicals
- g) Trips and Slips

**Question 26.** Multiple Select (Please circle all that apply)

In SafeDesign game, what aspects related to safety were you able to affect by completing the task of **construction site layout design**?

- a) Safe material storage
- b) Traffic control on site
- c) Visitor control
- d) Potentially hazardous material storage

- e) Fall from height
- f) Crane safety
- g) Weak management commitment to safety

**Question 26.** Could you recall some safety hazards and their mitigation measures from the **excavation** activity?

---

---

**Question 27.** Which aspects of safety were you able to affect as a SafeDesign game player in the **superstructure construction** activity? (*The superstructure of a building is the part that is entirely above its foundation or basement*)

---

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**Question 28.** Which aspects of safety were you able to affect as a SafeDesign game player in the **operation & maintenance** activity?

---

**Thank You!**

APPENDIX G

QUESTION BOOK FOR PAPER-BASED GAME INTERVENTION

Test ID:

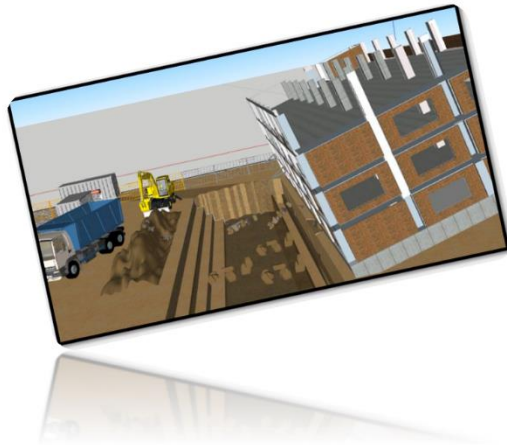


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# PREVENTION THROUGH DESIGN GAME

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## QUESTION BOOK



MARCH 16, 2017

**ARIZONA STATE UNIVERSITY**

## Question Book

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### **Instructions**

Read the problem situation described on each page. Then answer the questions about the situation. Do them one at a time. The questions will ask you to look at one or more scenarios. Follow the directions for each question and look at the appropriate scenario or scenarios, and then continue with the exercise. Do not jump ahead, but you may look back to earlier questions and your answers on the answer book provided. All questions direct you to choose only one answer.

After you have provided an answer to a question, look up the answer for that scenario on the answer book and see if your answer is correct and it will provide you with additional information. When you finish, you will learn how to score your performance.



## Question Book

---

### **Background**

You are a construction manager with five years' job experience and started your new job. Your employer Mr. Boss is losing money on his project due to poor safety condition causing frequent accidents. Mr. Boss asked you to inspect the project and identify as many hazards as possible. Each hazard costs roughly \$1000. If you identify a hazard correctly, your company will save \$1000. In case you failed to identify, it will lose \$1000. In order to keep your boss in business, try to identify hazards correctly and suggest reasonable solutions for managing the hazards. Please check your answers on the answer book and then evaluate your performance.

Turn the page and answer the first question.

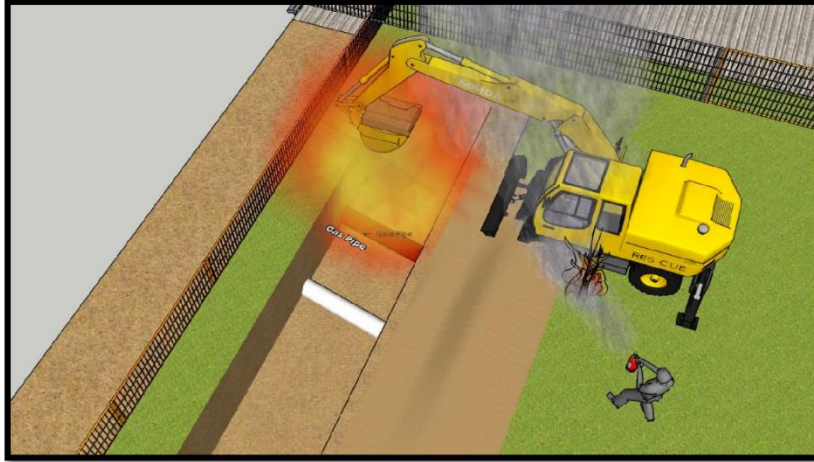
**Question Book**

**Scenario No. 1**

LOOK AT SCENARIO 1. This is a close-up view of the possible hazardous condition.



During excavating the foundations, the construction crew met with this situation shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



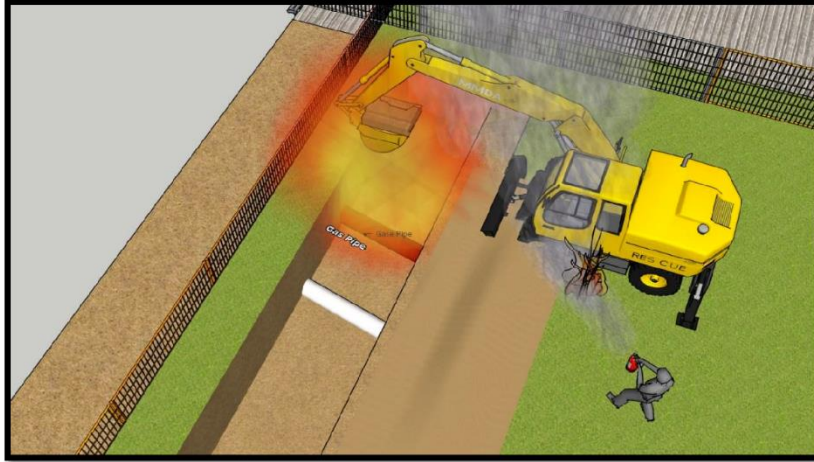
**Question Book**

**Scenario No. 1**

LOOK AT SCENARIO 1. This is a close-up view of the possible hazardous condition.



During excavating the foundations, the construction crew met with this situation shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



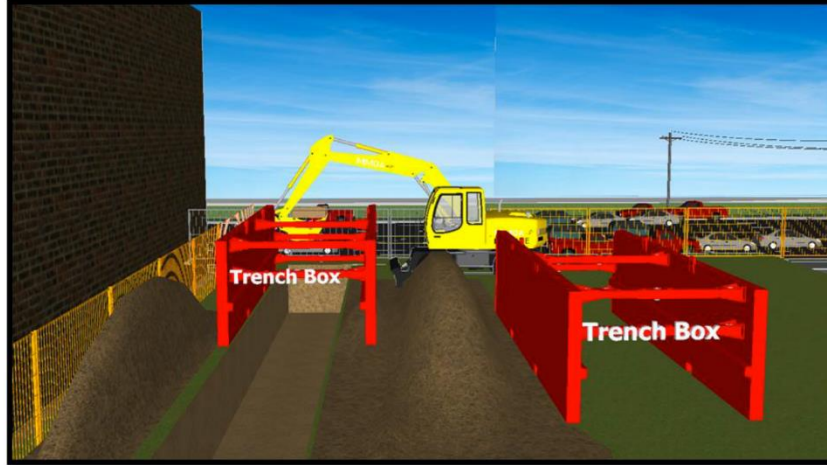
**Question Book**

**Scenario No. 2**

LOOK AT SCENARIO 2. This is a close-up view of the possible hazardous condition.



Your crew is trying to install a protective system in the trench.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 3**

LOOK AT SCENARIO 3. This is a close-up view of the possible hazardous condition.



Rainwater floods the construction site as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 4**

LOOK AT SCENARIO 4. This is a close-up view of the possible hazardous condition.



Heavy equipment is working on a large, deep excavation of wastewater treatment pond and the movement of the equipment could be a challenge as excavation is large, deep as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 5**

LOOK AT SCENARIO 5. This is a close-up view of the possible hazardous condition.



An excavator is excavating the foundation of a parking garage beside the foot of a hill.



Please write relevant answer code(s) from the Option Sheet to answer the questions below.

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code:

\_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code:

\_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



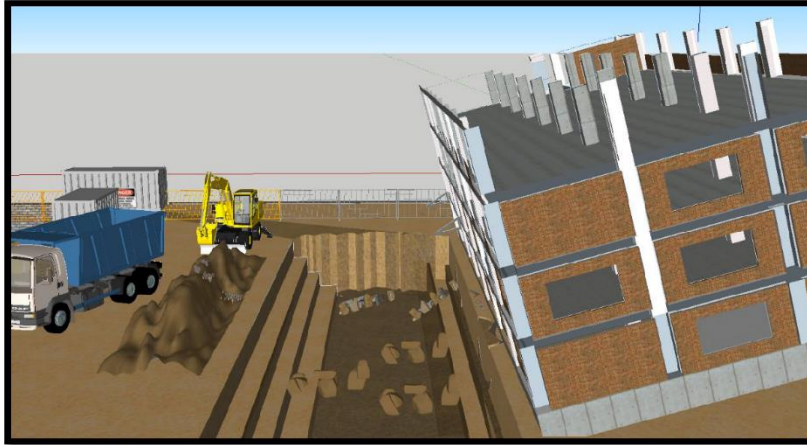
**Question Book**

**Scenario No. 6**

LOOK AT SCENARIO 6. This is a close-up view of the possible hazardous condition.



Your crew is excavating for a basement adjacent to the existing building foundations.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**





**Question Book**

**Scenario No. 7**

LOOK AT SCENARIO 7. This is a close-up view of the possible hazardous condition.



Your crew is placing the reinforcing steel for the construction of mat foundation. Workers have to walk on the top layer of reinforcing steel before concrete is poured.



Figure: Reinforcing Steel placed

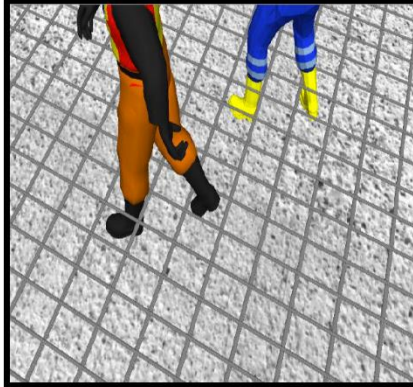


Figure: Workers walking on the reinforcing steel layer

**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code:

\_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code:

\_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 8**

LOOK AT SCENARIO 8. This is a close-up view of the possible hazardous condition.



The construction crew has stored material at the current location on the job site as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 10**

LOOK AT SCENARIO 10. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that many people are on the site. Not all of them are workers.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 11**

LOOK AT SCENARIO 11. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that there are multiple entry points to the job site.



Please write relevant answer code(s) from the Option Sheet to answer the questions below.

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



## Question Book

### Scenario No. 12

LOOK AT SCENARIO 12. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that public is using the adjacent walkway.



Please write relevant answer code(s) from the Option Sheet to answer the questions below.

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 13**

LOOK AT SCENARIO 13. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed construction material is scattered all over the place.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: \_\_\_\_\_
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 14**

LOOK AT SCENARIO 14. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that a painter is working inside the building as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 15**

LOOK AT SCENARIO 15. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that a painter is working at height inside the building as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**





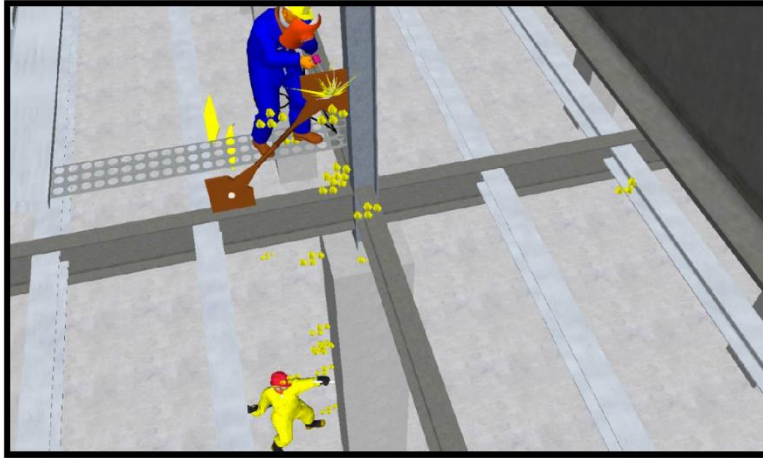
**Question Book**

**Scenario No. 16**

LOOK AT SCENARIO 16. This is a close-up view of the possible hazardous condition.



You, as a construction manager, found that a welder is working at height and a worker is working underneath the welder as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 17**

LOOK AT SCENARIO 17. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed a large quantity of material is stored inside the under-construction building.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



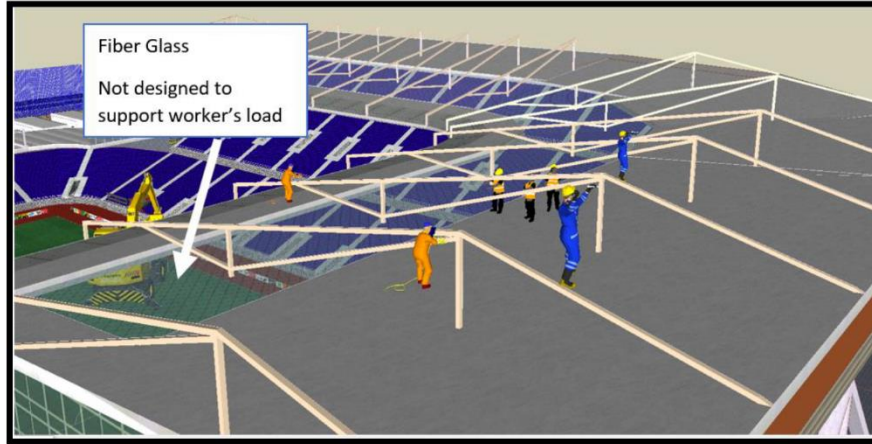
**Question Book**

**Scenario No. 18**

LOOK AT SCENARIO 18. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that workers are working on the roof of the stadium. The roof contains skylight sections which are not designed to carry body weight.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



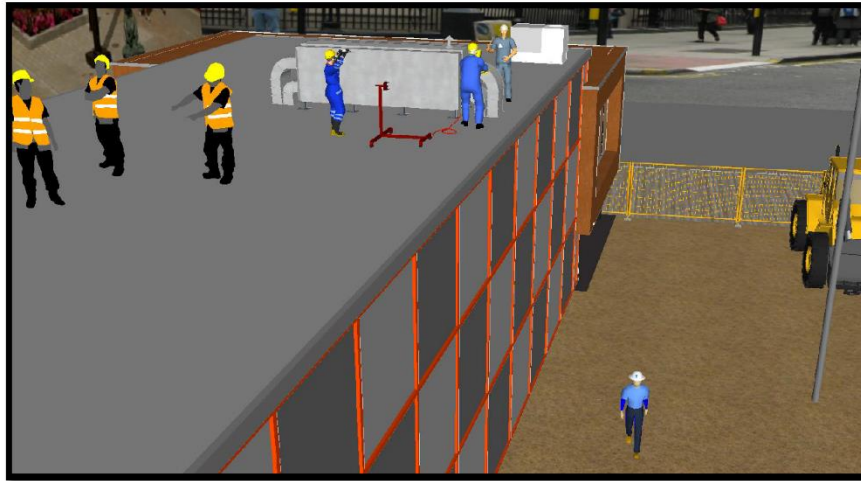
## Question Book

### Scenario No. 19

LOOK AT SCENARIO 19. This is a close-up view of the possible hazardous condition.



You, as a construction manager, observed that a crew is installing an air-conditioning equipment on the roof as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 20**

LOOK AT SCENARIO 20. This is a close-up view of the possible hazardous condition.



The windsock indicates that wind speed is very high, probably 30 mph.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: \_\_\_\_\_
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



## Question Book

### Scenario No. 21

LOOK AT SCENARIO 21. This is a close-up view of the possible hazardous condition.



The crew has poured the concrete into beams forms as shown below. After a certain time, the formwork will have to be stripped. If the formwork is removed prematurely from a beam or slab, then what are safety hazards due to early removal of formwork?



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: \_\_\_\_\_
- 3) I do not know.

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

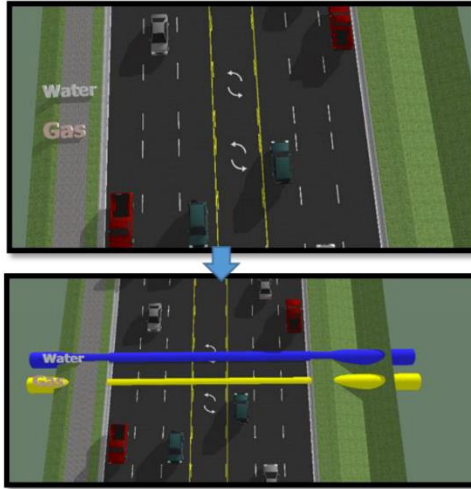
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**Scenario No. 22**

LOOK AT SCENARIO 22. This is a close-up view of the possible hazardous condition.



Your want to lay underground utility lines crossing the highway as shown below.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



**Question Book**

**Scenario No. 23**

LOOK AT SCENARIO 23. This is a close-up view of the possible hazardous condition.



You observed that several workers are working in very dim light indoors.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**





**Question Book**

**Scenario No. 24**

LOOK AT SCENARIO 24. This is a close-up view of the possible hazardous condition.



You observed that several workers are tired and look exhausted.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



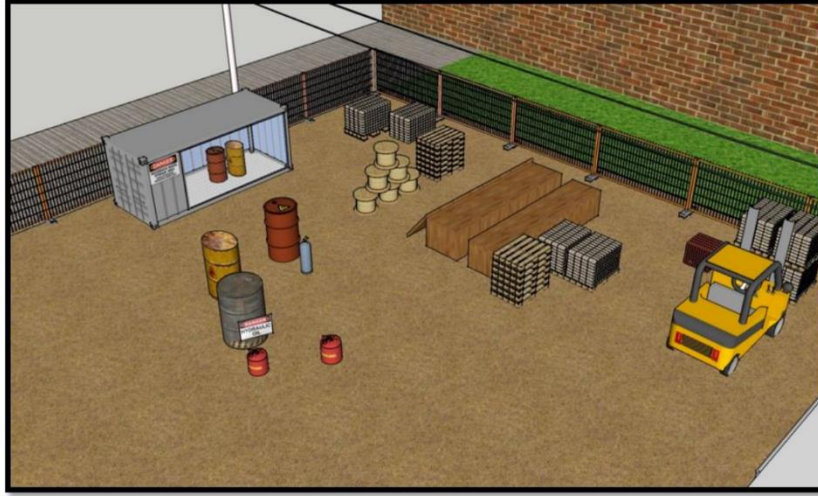
**Question Book**

**Scenario No. 25**

LOOK AT SCENARIO 25. This is a close-up view of the possible hazardous condition.



Some material on construction including hazardous chemicals and fuel liquids are scattered on the site.



**Please write relevant answer code(s) from the Option Sheet to answer the questions below.**

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: \_\_\_\_\_

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: \_\_\_\_\_

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE NEXT QUESTION.**



Question Book

**Your Performance**





HAZARDS

Number of Correct Answers to Question (a)	
Multiply by \$1000	\$

CONTROLS

Number of Correct Answers to Question (b)	
Multiply by \$1000	\$

<b>You Saved</b>		\$ <input type="text"/>
<b>You Lost</b>		\$50,000 - <input type="text"/> =

Thank you!

**WHEN YOU HAVE ANSWERED THE QUESTIONS, DO THE POSTTEST.**



## APPENDIX H

### OPTIONS FOR PAPER-BASED GAME INTERVENTION

Please select the relevant Code(s) from the table below to answer the questions in your question book.

Code	Choices for Question (a) - HAZARDS	Code	Choices for Question (b) - CONTROLS
1	Crashes in the work zone while laying underground utility pipe.	A	Avoid open cut method to install utility lines on busy highways.
2	Chemicals and Fuels left unattended – Fire hazard	B	Call 811 to mark utility lines before excavation starts.
3	The collapse of structural members such as beam due to premature removal of formwork.	C	Children are not allowed on the site.
4	A dusty environment can cause eye injuries, respiratory problem.	D	Controlled access & signage
5	Electric shock	E	Covered walkways
6	Electrocution	F	Dewatering
7	Excessive loss of water from the body.	G	During high wind speed, do not work on formwork erection.
8	Fall from height	H	Establish an access road
9	Fall to a lower level	I	Fix trench box by widening of the excavation.
10	Falling and flying objects	J	Housekeeping
11	Falling rocks can cause injury to workers and damage to equipment.	K	Install equipment on rooftop away from the roof edge and construct the parapet wall.
12	Falling sparks and hot slag	L	Install guardrails around surfaces not suitable for walking.
13	Fire hazard	M	Maintain three-point contact on the ladder
14	Injuries Due to Falls from Heights	N	Mark utility lines
15	No proper road access provided into the deep excavation.	O	Decide formwork stripping after verifying concrete test results.
16	The overcrowded construction site has more chances of accidents.	P	Mention design load on structure and drawings
17	Poor ventilation	Q	Minimize or control visitation of public
18	Rainwater can cause collapse of excavation walls.	R	Minimize work at height to reduce the risk of falling.
19	Road accidents in the work zone	S	No extensive overtime work
20	Structural failure due to excessive load on the floor slab	T	Paint before erection or installation of pipes
21	The injury or killing of workers with electric shock	U	Reinforcing steel spacing should not be more than 6 inches.
22	Too many visitors, trip hazards	V	Rock Fence or Retaining wall
23	Trench box does not fit well - No support for the walls and cave-in possible.	X	Schedule early installation permanent lighting system.
24	The trench may cave-in due to rainwater.	Y	Schedule work to prevent overcrowding and Impose a ceiling on the number of workers in a particular area.
25	Tripping hazard	Z	Shoring or place building away from the existing structure.
26	Uncontrolled access points	AA	Store hazardous material at the designated area.
27	Undermining the foundation	AB	Protect workers below from falling sparks or slag by proper scheduling the sequence of activities.
28	Weakened foundation, which can cause the structure to collapse.	AC	Store material away from powerlines.
29	Welding fumes	AD	Use Trenchless technology.
30	Workers may stumble or fall	AF	Use of facemask and ventilation system installation.

APPENDIX I

ANSWER BOOK FOR PAPER-BASED GAME INTERVENTION

Test ID:

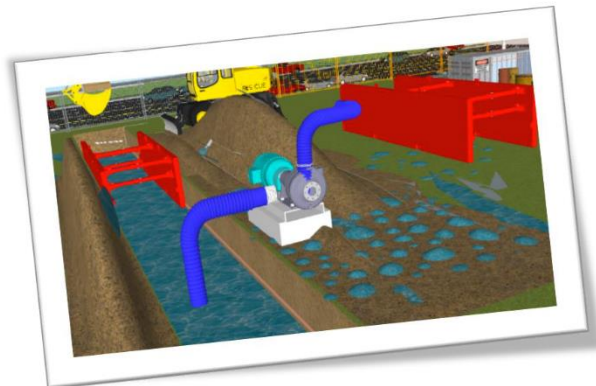


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# PREVENTION THROUGH DESIGN GAME

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## Answer Book



**MARCH 16, 2017**  
**ARIZONA STATE UNIVERSITY**

## Answer Book

### Scenario No. 1

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

1) I do not see any hazards; it is a normal activity.

2) I see hazards such as

Code: [5,13]. **Electrocution and Fire –The excavator may hit the utility line, resulting in fire and/or electric shock**

3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [N or B] **Mark utility lines or Call 811 to mark utility lines before excavation starts**

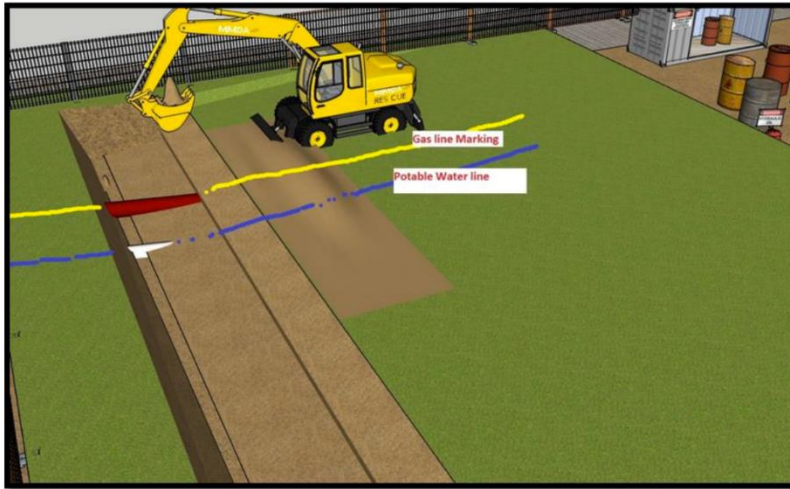


Figure 1. Mark underground utilities before excavation starts



## Answer Book

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### Scenario No. 2

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [23]. The trench box does not fit well and No support for the walls and cave-in possible.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [] Fix trench box by widening of the excavation

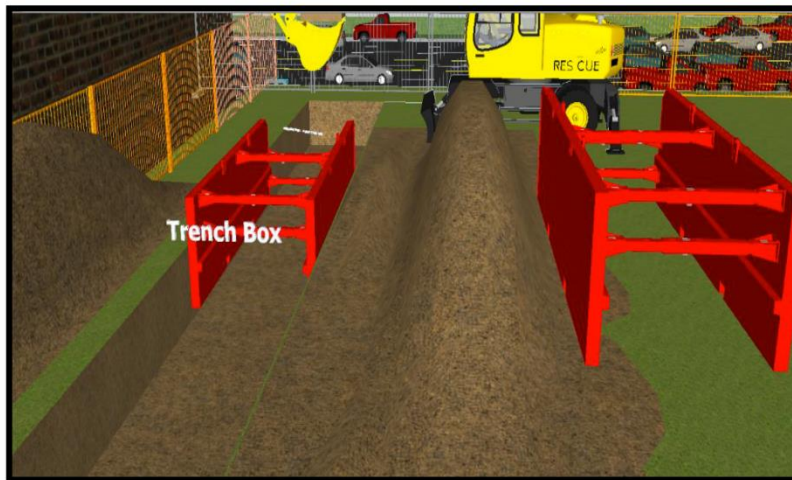


Figure 2. Trench box fits inside the excavation

## Answer Book

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### Scenario No. 3

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [24]. The trench may cave-in due to rainwater.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [F] Dewatering

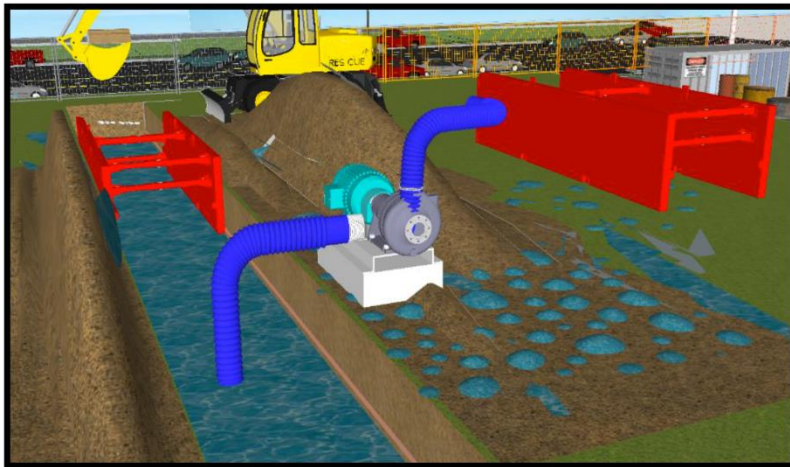


Figure 3. A pump installed to dewater the trench

## Answer Book

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### Scenario No. 4

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [15]. No proper road access provided into the deep excavation.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [H] Establish an access road

*Explanation: Provide road access into large, deep excavations such as wastewater treatment ponds and underground garages.*

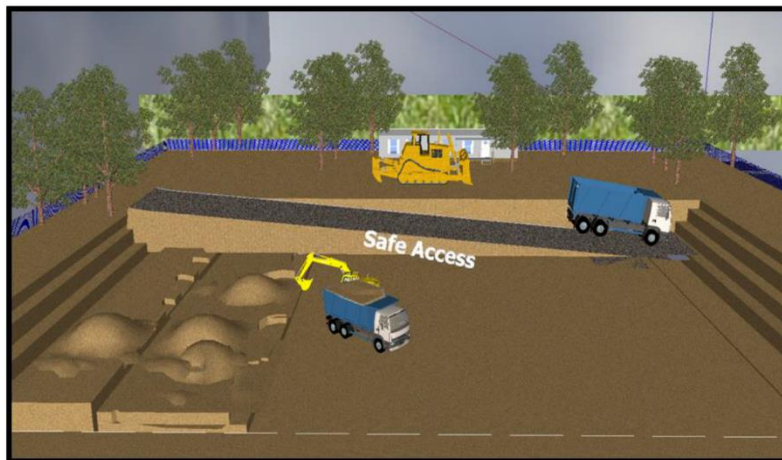


Figure 4. Road access is established

## Answer Book

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### Scenario No. 6

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [28]. Weakened foundation which can cause the structure to collapse.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [Z] Shoring or place building away from the existing structure

*Explanation: Locate new footings away from the existing foundations and install shoring to protect the existing structure as shown below.*



Figure 6. Shoring to protect the existing structure

## Answer Book

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### Scenario No. 7

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as
- 3) I do not know.

Code: [25]. Tripping hazard

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [U] Reinforcing steel spacing should not be more than 6 inches.

*Explanation: On the spread and continuous footings, and mat foundations, design the top layer of reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured.*

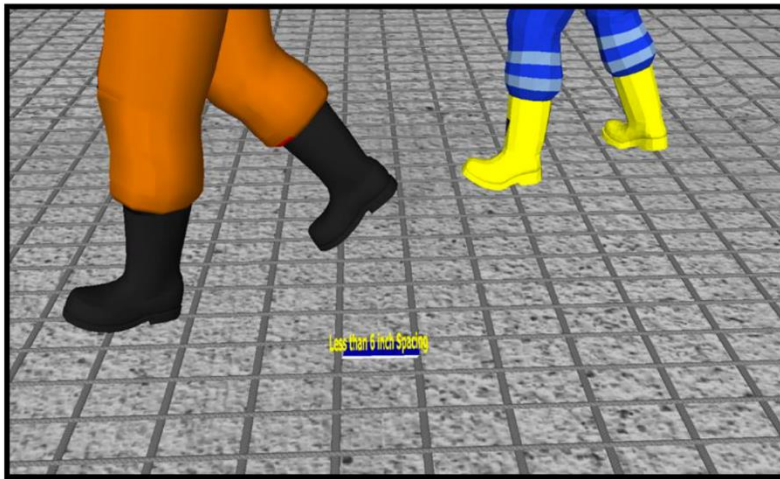


Figure 7. Reinforcing steel to be spaced no more than 6 inches

## Answer Book

### Scenario No. 8

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [5 or 6]. **Electrocution or Electric shock**
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [AC] **Store material away from powerlines.**

**Explanation:** Avoid material storage adjacent to power lines. Specifically, material storage should be at least fifty feet from any power lines



Figure 8. No material storage adjacent to power lines

## Answer Book

---

### Scenario No. 9

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [16]. The overcrowded construction site has more chances of accidents.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [Y]. Schedule work to prevent overcrowding and Impose a ceiling on the number of workers in a particular area.



Figure 9. Schedule activities to prevent overcrowding

## Answer Book

### Scenario No. 10

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.  
2) I see hazards such as

Code: [22 or 26]. Too many visitors, trip hazards or Uncontrolled access points.

- 3) I do not know.

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code:  
[Q and C].

Minimize or control visitation of public and Children are not allowed on the site

*Explanation: Minimize and control construction site visitation, and public access through and adjacent to the construction site. Moreover, all visitors must register at site office.*



Figure 10. Minimize and Control visitations and display signage



## Answer Book

### Scenario No. 11

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [26]. Uncontrolled access points.
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [D]. Controlled access & signage.

*Explanation: Controlled access points and display proper signage.*



Figure 11. Control multiple site entrances

## Answer Book

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### Scenario No. 12

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [10]. Falling and flying objects.
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [E]. Covered walkways

*Explanation: Provide covered walkways to protect public using walkways adjacent to under construction building.*



Figure 12. Covered walkway

## Answer Book

---

### Scenario No. 13

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [25]. Tripping hazard.
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [J]. Housekeeping

*Explanation: Require regularly scheduled site housekeeping to ensure a neat, clean and safe work area.*

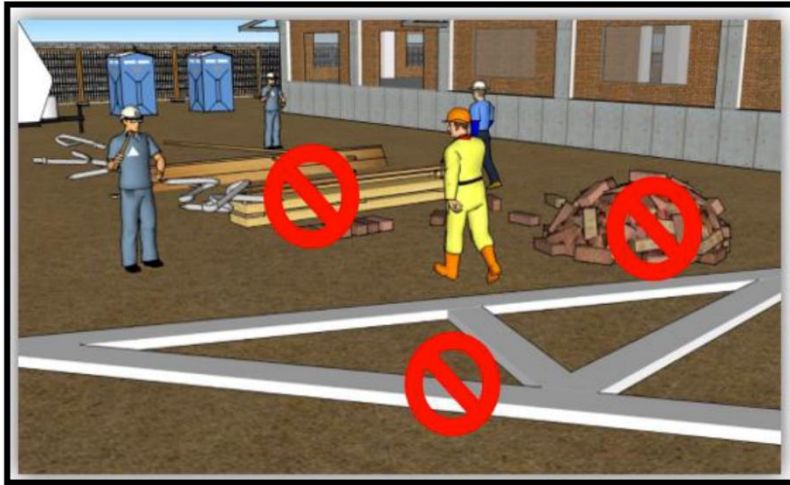


Figure 13. Clutter and obstacles that might cause someone to trip

## Answer Book

---

### Scenario No. 14

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [9 & 17]. Fall to a lower level & Poor ventilation.
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [M & AF]. Maintain three-point contact on the ladder & Use of face mask and ventilation system installed

*Explanation: Design and schedule ventilating systems to be in place in areas where coatings will be applied to help remove toxins from the air and also use a face mask. Also maintain three-point of contact on the ladder.*



Figure 14. Ventilation installed to remove toxins from the air

## Answer Book

---

### Scenario No. 15

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [8]. Fall from a height.
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [R or T]. Minimize work at height to reduce the risk of falling OR Paint before erection or installation of pipes.

*Explanation: Schedule materials, piping, and equipment to be painted and insulated before erection or installation to reduce worker exposures.*

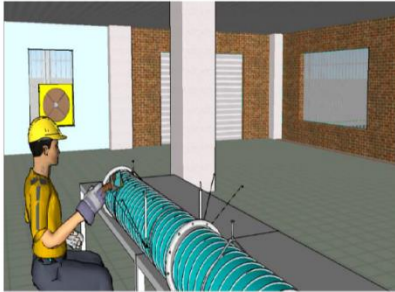


Figure 15 (a). Painting equipment at ground level



Figure 15 (b). Painting before installation

## Answer Book

---

### Scenario No. 16

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as
- 3) I do not know.

Code: [12 & 29]. *Falling sparks and hot slag and Welding fumes*

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [AB & AF]. *Protect workers below from falling sparks or slag by proper scheduling the sequence of activities & Use a face mask and ventilation system*

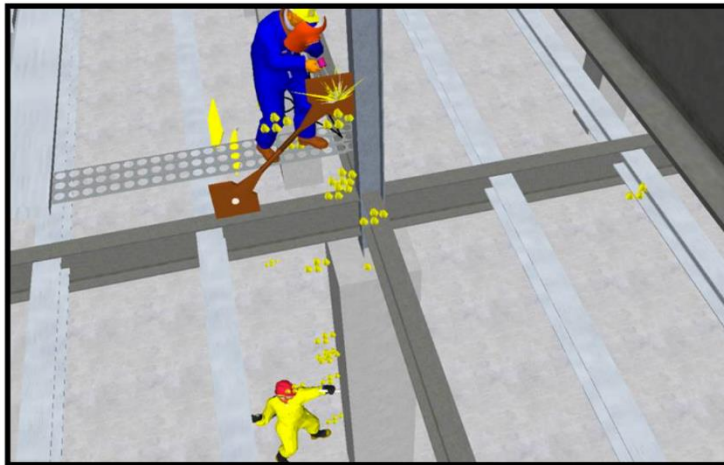


Figure 16. Protect worker below from falling sparks and slag

## Answer Book

---

### Scenario No. 17

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as
- 3) I do not know.

Code: [20]. Structural failure due to excessive load on the floor slab.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [P]. Mention design load on structure and drawings.

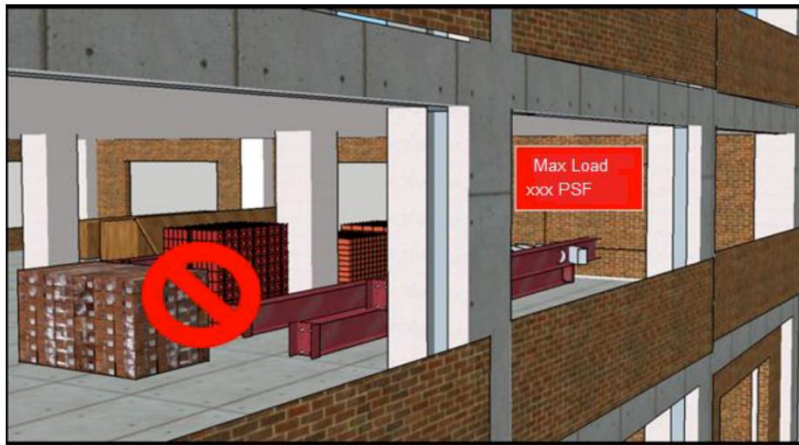


Figure 17. Mention design load to prevent overloading

## Answer Book

### Scenario No. 18

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as
- 3) I do not know.

Code: [8]. Fall from height

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [L]. Install guardrails around surfaces not suitable for walking.

*Explanation: When specifying roofing materials which are not suitable for walking, such as corrugated fiberglass panels, ensure they are distinguishable from safe, secure walking surfaces on the roof, or install guardrails around surfaces not suitable for walking.*

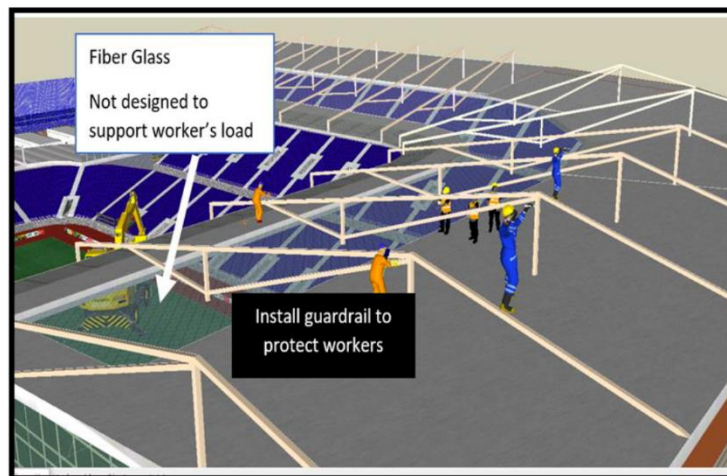


Figure 18. Provide guardrail systems to prevent workers from stepping on the non-load bearing roof sections (Skylights)



## Answer Book

---

### Scenario No. 19

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [B]. Fall from height
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [K]. Install equipment on rooftop away from the roof edge and also construct parapet wall

*Explanation: To reduce fall hazards, locate rooftop mechanical/HVAC equipment away from the roof edge and also construct parapet wall.*

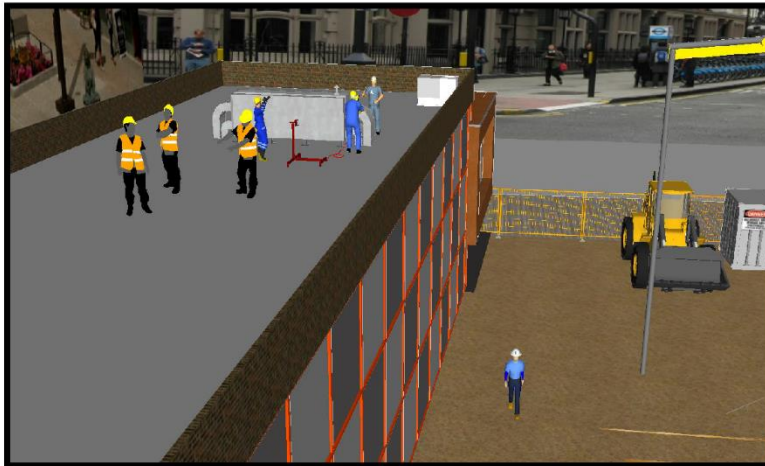


Figure 19. Locate rooftop equipment away from the roof edge and construct parapet wall

## Answer Book

### Scenario No. 20

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as  
Code: [10]. Falling and flying objects
- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [G]. During high wind speed, do not work on formwork erection.

*Explanation: Prohibit forming work by hand if wind speed exceeds 30 miles per hour.*



Figure 20. Formwork placement and high wind speed

## Answer Book

### Scenario No. 21

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [3].

The collapse of structural members such as beam due to premature removal of formwork.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [0].

Decide formwork removal time after verifying concrete test results

*Explanation: Require concrete test results to be verified before formwork stripping and removal of shoring, as structural collapse might occur if forms are stripped prematurely.*

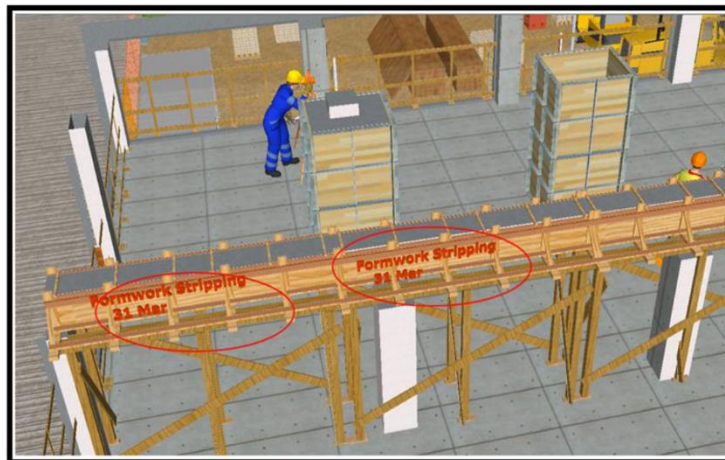


Figure 21. Decide formwork removal time after verifying concrete test results

## Answer Book

### Scenario No. 22

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [1]. Crashes in the work zone while laying underground utility pipe.

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [A or AD]. Avoid open cut method to install utility lines on busy highways or Use trenchless technology

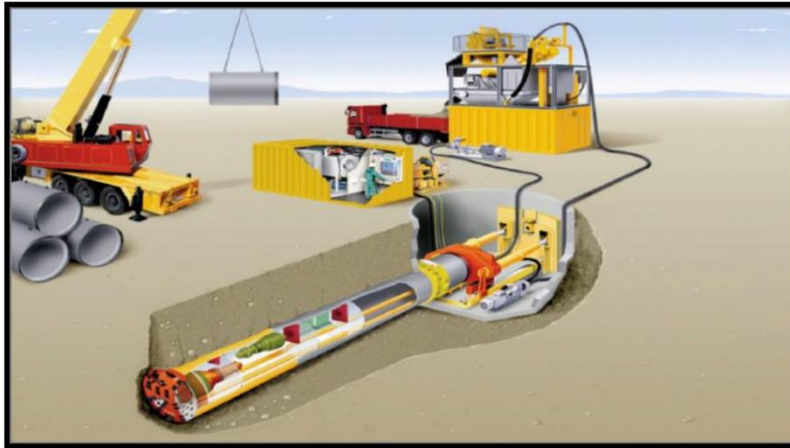


Figure 22. Use of trenchless technology to lay underground utility pipelines

## Answer Book

---

### Scenario No. 23

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as
- 3) I do not know.

Code: [25].      Tripping hazard due to low light.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [X].      Schedule early installation permanent lighting system

*Explanation: Schedule permanent lighting systems to be installed early in the construction phase and available for use by the constructor.*



Figure 23. Schedule permanent lighting systems to be installed early

## Answer Book

---

### Scenario No. 24

- a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.  
2) I see hazards such as

Code: [7]. Excessive loss of water from the body.

- 3) I do not know.

- b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [S]. No extensive overtime work.

*Explanation: To prevent accidents resulting from tired construction workers, do not allow schedules which require workers to work extensive overtime.*



Figure 24. Workers exhausted

## Answer Book

### Scenario No. 25

a. Can you identify safety hazards in the given scenario?

Choose only ONE!

- 1) I do not see any hazards; it is a normal activity.
- 2) I see hazards such as

Code: [2]. Chemicals and Fuels left unattended – Fire hazard

- 3) I do not know.

b. If you have identified safety hazards in the given scenario, how will you control them?

Code: [AA]. Store hazardous material at the designated area

*Explanation: To prevent accidents resulting from tired construction workers, do not allow schedules which require workers to work extensive overtime.*

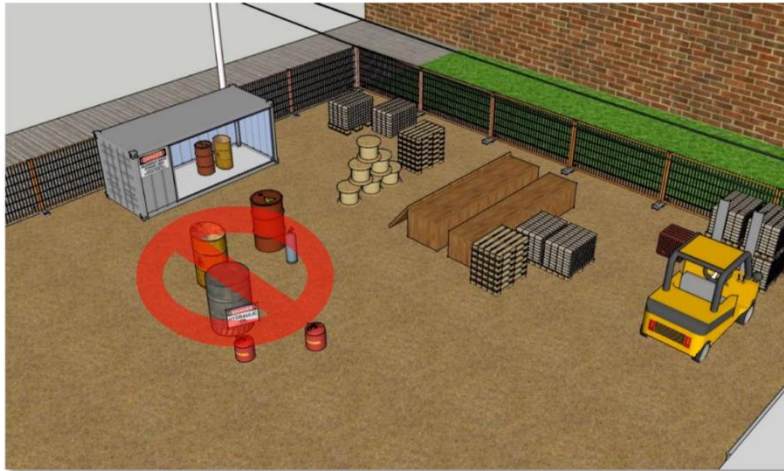


Figure 25. Store hazardous material at a designated place

**Answer Book**

---

**Scores**

**Total Hazards = 25**

**Total Controls = 25**

**Total savings = 50 x \$1000 = \$50,000 and Many Lives of Workers**



**The End**



## APPENDIX J

### SCREENSHOTS OF THE SAFEDESIGN GAME INTERVENTION

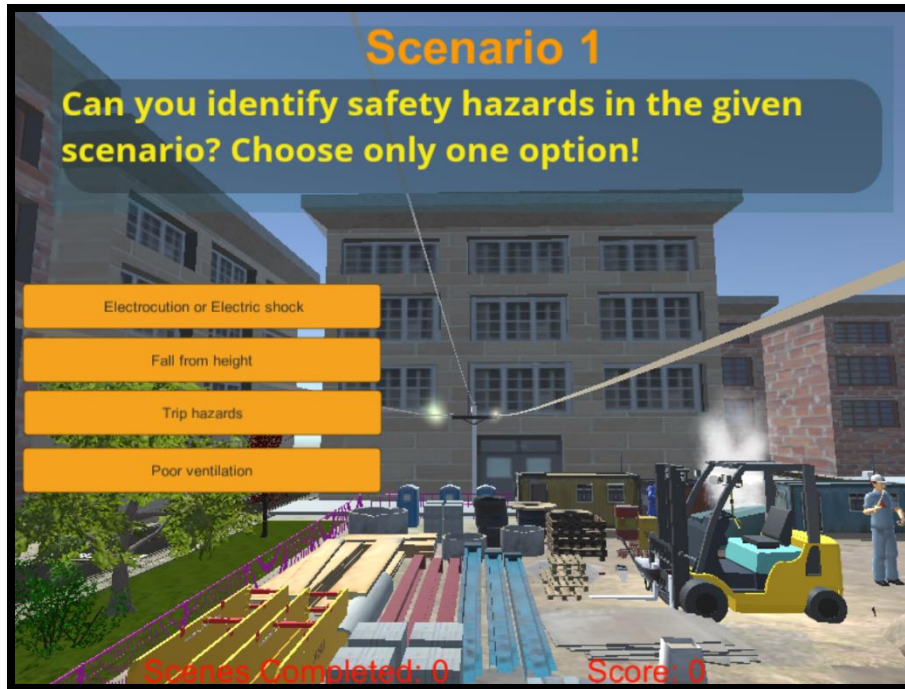


Figure: Hazard identification

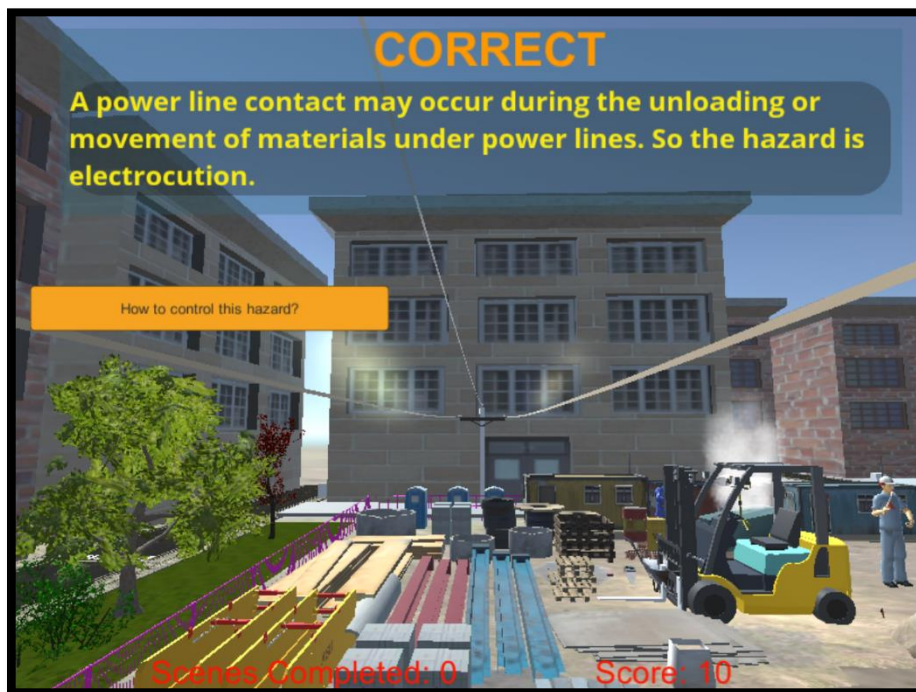


Figure: Hazard identification feedback



Figure: Control identification



Figure: Hazard identification feedback

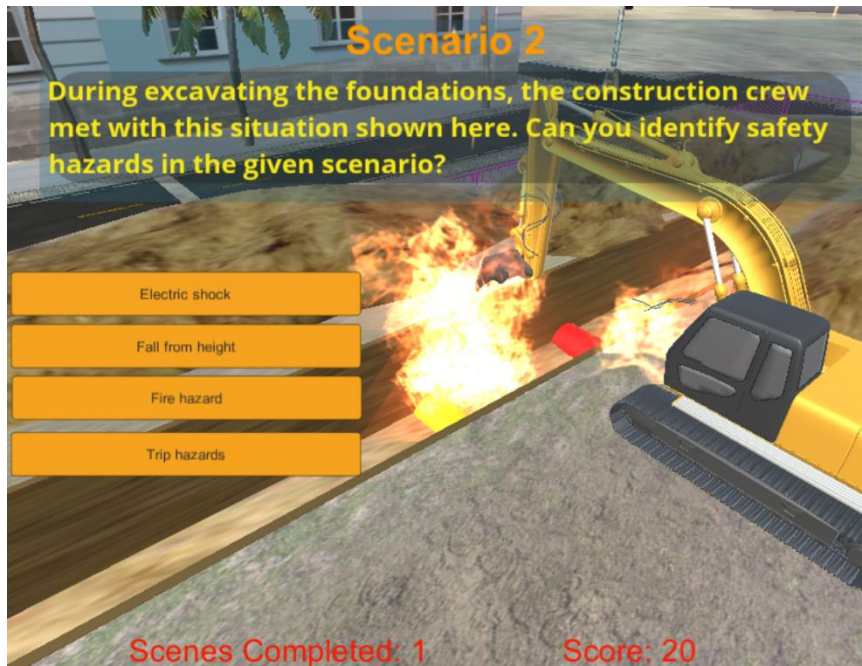


Figure: Excavation hazards



Figure: Excavation hazards feedback (The selected was wrong)



Figure: Hazards due to overcrowded site



Figure: Hazard control options

APPENDIX K

HANDOUTS FOR THE PTD IN-CLASS LECTURE INTERVENTION



## Architectural Design, Construction and Structural Design

Edited and Presented by:  
**Zia Ud Din**  
Arizona State University



Developed by Michael Behm, Ph.D.  
Cory Soughton  
East Carolina University



## Overview

- PtD concept
- Site planning
- Excavation
- Building elements
- General considerations
- **Decommissioning**



Photo courtesy of Thinkstock





## Learning Objectives

- Explain the Prevention through Design (PtD) concept.
- List reasons why project owners may wish to incorporate PtD in their projects.
- Identify workplace hazards and risks associated with design decisions and recommend design alternatives to alleviate or lessen those risks.



## Introduction to Prevention through Design EDUCATION MODULE







## Construction Hazards

- Cuts
- Electrocution
- Falls
- Falling objects
- Heat/cold stress
- Musculoskeletal disease
- Tripping



Graphic courtesy of OSHA

[BLS 2006; Lipscomb et al. 2006]



## Design as a Risk Factor: Australian Study, 2000–2002

- Main finding: design contributes significantly to work-related serious injury
- 37% of workplace fatalities are due to design-related issues
- In another 14% of fatalities, design-related issues may have played a role



Photo courtesy of Thinkstock

[Driscoll et al. 2008]





## Accidents Linked to Design

- 22% of 226 injuries that occurred from 2000 to 2002 in Oregon, Washington, and California were linked partly to design [Behm 2005]
- 42% of 224 fatalities in U.S. between 1990 and 2003 were linked to design [Behm 2005]
- In Europe, a 1991 study concluded that 60% of fatal accidents resulted in part from decisions made before site work began [European Foundation for the Improvement of Living and Working Conditions 1991]
- 63% of all fatalities and injuries could be attributed to design decisions or lack of planning [CHAIR safety in design tool 2001]

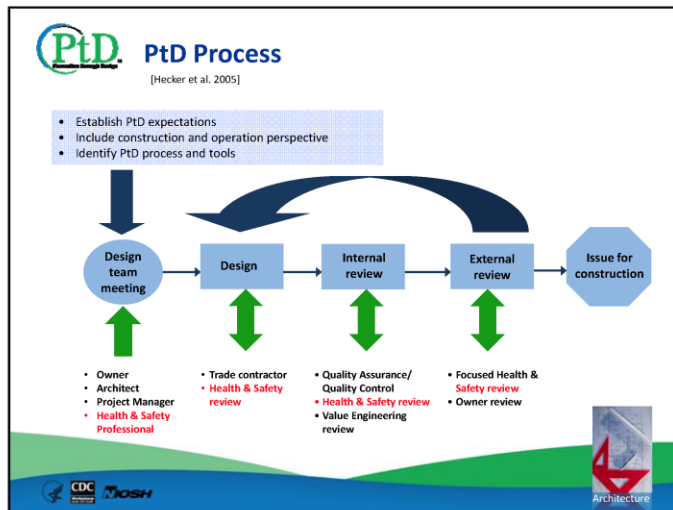
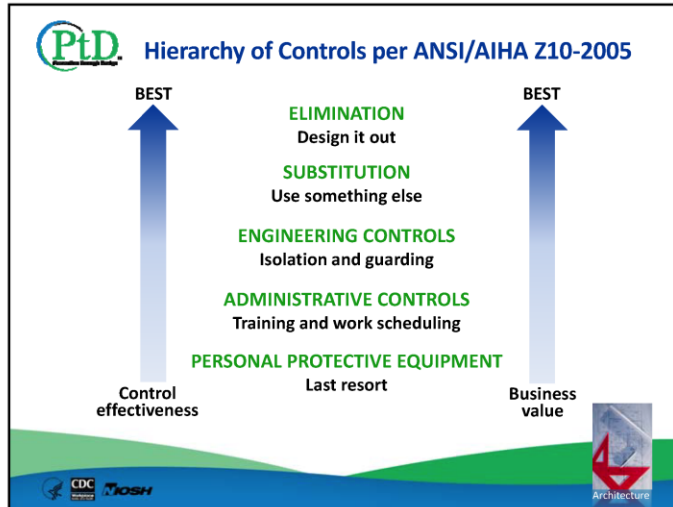


## What is Prevention through Design?

Eliminating or reducing work-related hazards and illness and minimizing risks associated with

- Construction
- Manufacturing
- Maintenance
- Use, reuse, and disposal of facilities, materials, and equipment







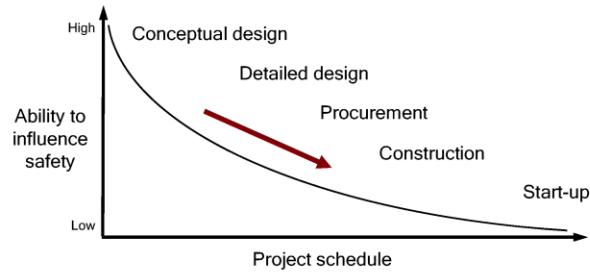
## Integrating Occupational Safety and Health with the Design Process

Stage	Activities
Conceptual design	Establish occupational safety and health goals, identify occupational hazards
Preliminary design	Eliminate hazards, if possible; substitute less hazardous agents/processes; establish risk minimization targets for remaining hazards; assess risk; and develop risk control alternatives. Write contract specifications.
Detailed design	Select controls; conduct process hazard reviews
Procurement	Develop equipment specifications and include in procurements; develop "checks and tests" for factory acceptance testing and commissioning
Construction	Ensure construction site safety and contractor safety
Commissioning	Conduct "checks and tests," including factory acceptance; pre-start up safety reviews; development of standard operating procedures (SOPs); risk/exposure assessment; and management of residual risks
Start up and occupancy	Educate; manage changes; modify SOPs



## Safety Payoff During Design

[Adapted from Szymberski 1997]





## Example Checklist as a Tool

Item	Description
<b>1.0</b>	<b>Structural Framing</b>
1.1	Space slab and mat foundation top reinforcing steel at no more than 6 inches on center each way to provide a safe walking surface.
1.2	Design floor perimeter beams and beams above floor openings to support lanyards.
1.3	Design steel columns with holes at 21 and 42 inches above the floor level to support guardrail cables.
<b>2.0</b>	<b>Accessibility</b>
2.1	Provide adequate access to all valves and controls.
2.2	Orient equipment and controls so that they do not obstruct walkways and work areas.
2.3	Locate shutoff valves and switches in sight of the equipment which they control.
2.4	Provide adequate head room for access to equipment, electrical panels, and storage areas.
2.5	Design welded connections such that the weld locations can be safely accessed.

[Checklist courtesy of John Gambatese]



## PtD Applies to Constructability

- How reasonable is the design?
  - Cost
  - Duration
  - Quality
  - Safety



Photo courtesy of the Cincinnati Museum Center [www.cincinnati-museum.org](http://www.cincinnati-museum.org)





## Benefits of PtD

- Reduced site hazards and thus fewer injuries
- Reduced workers' compensation insurance costs
- Increased productivity
- Fewer delays due to accidents
- Increased designer-constructor collaboration
- Reduced absenteeism
- Improved morale
- Reduced employee turnover



## Site Planning





## Site Location and Access

- Materials
- Workers
- Equipment
- Pedestrians



Photo courtesy of Thinkstock



## Prefabrication

- Prefabrication and preassembly will likely increase worker safety [Haas 2000]
- Prefabrication reduces work at height [CIRIA 2004]
- Prefabrication may reduce cold/heat stress
- Prefabrication increases heavy lifting; possible access and transportation issues
  - Managing risks is the key





### Example: Prefabricated Truss

- Fewer connections to make in the air
- Safer and faster



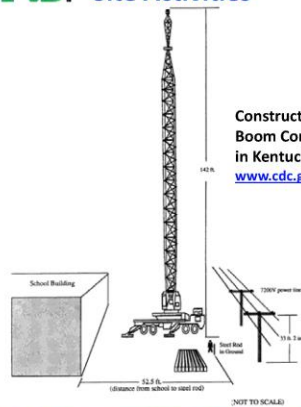
*Photo courtesy of Thinkbox*



### Site Activities

Construction Laborer is Electrocuted When Crane Boom Contacts Overhead 7200-volt Power line in Kentucky

[www.cdc.gov/niosh/face/In-house/full9121.html](http://www.cdc.gov/niosh/face/In-house/full9121.html)







## Cranes and Derricks

- Carefully plan erection and disassembly
- Site layout affects crane maneuverability
- Show site utilities on plans
- Comply with OSHA standards



Photo courtesy of Walter Heibel

OSHA comprehensive crane standard: [www.osha.gov/FedReg\\_osha\\_pdf/FE020100809.pdf](http://www.osha.gov/FedReg_osha_pdf/FE020100809.pdf)  
Regulation text: [www.osha.gov/cranes-derricks/index.html](http://www.osha.gov/cranes-derricks/index.html)



## Excavations



**PtD** Excavation

- U.S. Bureau of Labor Statistics (BLS) data show that 271 workers died in trenching or excavation cave-ins from 2000 through 2006 [BLS 2003-2009]
- Project designers have a role to play in excavation safety.



**PtD** Wet Conditions Increase Risk



Photos courtesy of Thinkstock





## Driller's Helper Electrocuted

Safety tips to live by:

1. Watch for overhead dangers
2. Be aware of your surroundings
3. Know the machine capacity
4. Always secure loads
5. Drive safely
6. Be safe and smart



Alaska FACE Investigation 98A019 [www.cdc.gov/niosh/Topic/Interference/98A019.html](http://www.cdc.gov/niosh/Topic/Interference/98A019.html)



## Building Elements



**PtD.** Parapets

The parapet will serve as adequate fall protection if it is at least 39" high.



Photo courtesy of Mike Behm



**PtD.** Railings Prevent Falls



Photo courtesy of Thinkstock



## Anchor Points

- Part of the facility
- Use during construction and maintenance
- OSHA standard regarding anchorages can be found in 29 CFR 1926.502(d)(15)



Photo courtesy of Thinkstock



## Ability to Support Lifelines

- Design beams near or above openings to be able to support lifelines
- Contract drawings should make clear how many lifelines each beam can support, and at what locations they can be attached



Photo courtesy of Thinkstock

[Gambatese 1996; NISD and SEAA 2009; OSHA 29 CFR 1926.502(d)(15)]





## Walkways on Roof

Fragile roofing poses hazards to workers who need rooftop access

*Electrician Dies Following a 60-foot Fall Through a Roof—Virginia, FACE 9605*  
[www.cdc.gov/niosh/face/in-house/full9605.html](http://www.cdc.gov/niosh/face/in-house/full9605.html)

Walkway guardrails designed as a barrier from fragile materials



Photo courtesy of the Virginia Division of Safety Research



## Formwork

- It is customary to prohibit forming work by hand if wind speed exceeds 25 mph
- Limit the lift height of concrete pours to minimize the load on formwork and the risk of collapse of fresh concrete during pouring operations



Photo courtesy of John Gambatore



## Formwork

- For complicated and large formwork designs, specify that formwork calculations and drawings must be reviewed and stamped by a licensed engineer
- Specify the minimum compressive strength for removal of elevated forms if different than the design compressive strength of the concrete
  - Prevents collapse of the structure due to early removal of the forms



## Skylights

In 2003, worker deaths included these falls:

- 23 through skylights
- 11 through existing roof openings
- 24 through existing floor openings

Most of these deaths occurred in the construction industry.  
[BLS 2003–2009]





## Fatality During Skylight Installation



Photo courtesy of the California Department of Public Health

An Electrical Worker Dies When He Falls Through a Skylight While Installing Solar Panels on the Roof of a Warehouse [www.cdc.gov/niosh/faces/stateface/ca/09:ca003.html](http://www.cdc.gov/niosh/faces/stateface/ca/09:ca003.html)



## Unguarded Flat Skylight



Photo courtesy of the Wisconsin Department of Public Health

Laborer Dies From Fall Through Skylight While Shoveling Snow on Roof [www.cdc.gov/niosh/faces/stateface/wj/99/W1002.html](http://www.cdc.gov/niosh/faces/stateface/wj/99/W1002.html)





**PtD.** Skylight with Guard Cage

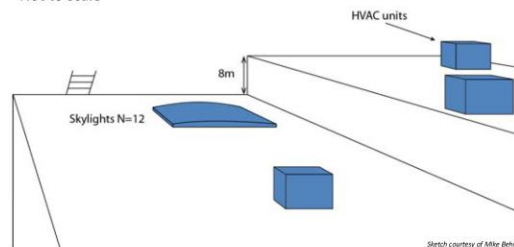


*Photo courtesy of Plastico*



**PtD.** Sketch of Rooftop

Not to scale





*Sketch courtesy of Mike Behm*



**PtD** **Green Roof Safety Design**  
 [Weiler and Scholtz-Barth 2009]

Issues	Design Ideas
Access for people, tools, materials	Fixed stairs inside, designated walkways
Ergonomics	Allow adequate space to work. Include on-site storage for tools, fertilizers, etc.
Falls at building edge	Parapets, lifelines, anchorage systems
Falls in roof openings	Guard skylights and other roof openings
Fire, wind uplift	Vegetation-free zones
Maintenance	Plant-selection strategies
Rooftop machinery hazards	Machinery guards

**PtD** **Installing Rails for Solar Panels**

How could this man work safer?



Photo courtesy of Thinkstock






## Windows and Atria

How would you wash these windows or replace a broken pane?



Photo courtesy of Thinkstock



## Unsafe Window Maintenance



Photo courtesy of Thinkstock





## Window Access System

Safe access for cleaning and maintenance of the facility should be considered during the design phase.



Photo courtesy of Thinkstock



## General Considerations



## Material Handling

Heavy blocks are a significant musculoskeletal hazard, causing many injuries, but are an easy design issue to resolve.



Photo courtesy of Thinkstock



## Fatigue

- To prevent accidents resulting from tired construction workers, do not allow schedules which require workers to work extensive overtime.





## Surface Coatings and Finishes

- Why apply?
- Must be sprayed?
- Materials compatible?
- Working space?
- Ventilation?
- Pretreat materials?
- Handling issues?
- Access issues?
- Is there a need for respiratory protection?



Photo courtesy of Thinkstock

This worker wears protection against finish hazards.



## ARCHITECTURAL DESIGN AND CONSTRUCTION Building Decommissioning



**PtD** Demolition



Photo courtesy of Thinkstock



**PtD** Refurbishment

During remodeling, minimize risks to

- Eyes: Safety glasses
- Skin: Long sleeves, pants, shoes and socks
- Hands: Gloves
- Ears: Earplugs
- Head: Hardhat
- Nose & Mouth: Face mask
- Lungs: Exhaust fan



Photo courtesy of Thinkstock





## Recap

- **Prevention through Design (PtD)** is an emerging process for saving lives, time, and money and for protecting workers' health.
- PtD is the smart thing to do and the right thing to do.
- Although site safety is the contractor's responsibility, the designer has the ethical duty to create drawings with good constructability.
- There are tools and examples to facilitate PtD.



## Help make the workplace safer...

Include *Prevention through Design* concepts in your projects.

For more information, please contact the National Institute for Occupational Safety and Health (NIOSH) at

Telephone: (513) 533-8302

E-mail: [preventionthroughdesign@cdc.gov](mailto:preventionthroughdesign@cdc.gov)

Visit these NIOSH Prevention through Design Web sites:

[www.cdc.gov/niosh/topics/PtD/](http://www.cdc.gov/niosh/topics/PtD/)

[www.cdc.gov/niosh/programs/PtDesign/](http://www.cdc.gov/niosh/programs/PtDesign/)







Thank you for your time



APPENDIX L

INFORMATION AND CONSENT FORM

## Consent Form

### **IRB ID: STUDY00005528**

**Title of research study:** *Teaching Prevention through Design (PtD) Principles Using a Non-Traditional Pedagogical Strategy*

**You are invited to participate in a research study** to attempt to determine whether or not the use of a serious game as an instructional method is as or more effective than a paper-based game and the traditional instructional technique of in-class lecture.

Additionally, we would like to determine whether or not certain student populations, as determined by engagement, game-play frequency, and preferred learning style, would benefit from the use of serious games. The study is being conducted by Zia Ud Din, Doctoral Candidate, under the direction of Dr. G. Edward Gibson, Jr., Professor and Director of the School of Sustainable Engineering and the Built Environment, Arizona State University. You are selected as a possible participant because you are enrolled in one of the courses selected to be surveyed in this study and are age 18 or older.

**What will be involved in the study?** You will be asked to complete a pretest; receive instructions via lecture, paper version of the game, or computer game (also referred to as a serious game); and complete a post-test. You will also be requested to complete a follow-up survey after three weeks of the activity. Your total time will be approximately 60 minutes.

**Are there any risks and discomforts?** The risks associated with participating in this study are a breach of confidentiality and coercion. To minimize the risk of breach of confidentiality, participants will not be required to put their names on the documents. Each participant will be randomly assigned a participant identification number in order to protect their identity. We will also securely store all information, which can be linked back to the participant. Upon completion of the study, all identifying data will be destroyed. Additionally, the number of participants we intend to involve in the study

should minimize the risk of breach of confidentiality. To avoid the risk of coercion, all of the instructors of the courses involved in the study have agreed that no extra credit will be given as an incentive for completing the tests. Your presence in the class will count towards your attendance, but you have the right to refuse to provide your data for the research activity. You also have the right to skip or not answer any or all of the questions that you prefer.

**Will you receive compensation for participating?** To thank you for your time you will be offered inclusion in a raffle for two \$50 Walmart gift cards. Chances of winning the raffle are 2:130, depending on the number of participants in the study.

**Are there any costs?** You will not incur any costs.

**If you change your mind about participating in the research,** you can withdraw your data as long as it is identifiable at any time during the study. Your choice to provide your data for the research is voluntary. Your decision about whether or not to provide data or to withdraw your data will not jeopardize your future relations with Arizona State University or the department involved in this study.

**Any data obtained in connection with this study will be securely saved.** We will protect your privacy, and the data you provide will be protected by use of a coding system to add a level of confidentiality between the data set and any identifying information found on the research instruments. All original copies of the data collection instruments will be kept in a secure location and will be destroyed either after one year or the lifetime of the approval of this study. Information collected through your participation will be used to fulfill the educational requirements for a Ph.D. in Civil Engineering and may be used in journal publications or presentations at professional meetings.

**If you have questions about this study,** contact Zia Ud Din at [ziauddin@asu.edu](mailto:ziauddin@asu.edu) (480-558-6233) or Dr. G. Edward Gibson, Jr. at [GEwardGibsonJr@asu.edu](mailto:GEwardGibsonJr@asu.edu) (480-965-7972).

Having read the information provided, you must decide if you want to participate in this research project. If you decide to participate, the data you provide will serve as your agreement to do so. This letter is yours to keep.

\_\_\_\_\_  
Signature of person obtaining consent  
Date

\_\_\_\_\_  
Zia Ud Din  
Print Name

\_\_\_\_\_  
Participant's signature  
Date

\_\_\_\_\_  
Print Name

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the Office of Research Integrity and Assurance, at (480) 965-6788 or by email at [research.integrity@asu.edu](mailto:research.integrity@asu.edu).

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## Consent form

**IRB ID : STUDY00005528**

### **To Whom It May Concern:**

All of my questions have been answered; I am over the age of 18, and I wish to participate in this research study. I have received a copy of this consent form to keep for my records.

I will be asked to complete a pretest; receive instructions via lecture, paper version of the game, or computer game (referred to as a serious game); and complete a post-test.

I look forward to contributing enhancing the safety and wellbeing of the construction workforce through my participation in this study.

Sincerely,

---

Participant's Signature \_\_\_\_\_ Date \_\_\_\_\_ Print Name (Last Name, First Name)