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Developing and Testing Training Tools for Fall Protection in Construction

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Abstract

The major cause of fatal injuries in construction is due to falls, and their occurrence has only increased over the years. Ineffective and low-engaging methods used to deliver construction safety training content are among the major factors contributing to high injury rates. This can be prevented through more effective safety training. Serious Games are interactive training tools used with modern computer applications that offer engagement missing in traditional construction safety training methods. This paper aims to develop and test a construction safety training Serious Game titled, FallSafe, that focuses on fall protection training. FallSafe is implemented in Virtual Reality to create a life-like training experience and uses a first-person perspective and storyline to engage the player in reporting on-site hazards as a construction safety intern attending their first day of work on site. The implementation of a Serious Game framework during the development of FallSafe ensures consistent delivery of desired learning outcomes. FallSafe pilot-tested six students and is found to be an engaging and effective method of construction safety training and received praise for its storyline, interactivity, and use of Virtual Reality technology to deliver construction safety training. FallSafe has the potential to be further developed, tested, and implemented to teach construction safety on a large scale which could help prevent injury and death on the site and decrease costs to firms.

Keywords: Training Procedures; Serious Games; FallSafe; Interactivity; Virtual Reality

Introduction

There is evidence that suggests current construction safety training is ineffective and often taught through low-engaging methods (Burke et al. 2006, Shamsudin et al. 2018). These inadequacies result in great costs to employers and society (Wilkins 2011). A review of current research on the engagement provided by e-learning versus traditional methods of teaching construction safety training reveals that highly engaging teaching tools result in greater knowledge retention. The idea of developing an interactive, engaging, and, therefore, more effective method of construction safety training in the form of a Serious Game using Virtual Reality is the basis for this paper. A review of selected construction industry surveys and investigations reveals that a lack of proper safety training often occurs before workplace mishaps, resulting in worker injuries and deaths [1-3]. Studies have found several shortcomings regarding the construction industry's current health and safety training.

There is an increase in investment by construction firms toward improving the quality of existing training programs, pointing out that only 2.2% of the price of a facility is devoted to safety efforts. Safety training is cost-effective for firms are essential to prioritize accident and injury prevention. Safety training through digital learning is economically beneficial to companies and in providing effective training for construction workers. An added Virtual Reality component will create a hands-on and highly interactive environment, it is the next closest training experience to on-site learning [4-7].

This study's purpose is to develop a construction safety training Serious Game implemented in Virtual Reality, with a focus on hazard recognition, to enhance knowledge retention and promote safe behavior in construction.

Research Goal and Objectives

This study aims to develop an interactive and engaging safety training module in the form of a Serious Game and then to pilot test that Serious Game. The purpose of pilot testing the game is to receive feedback from participants that will help further advance game- development and enhance the delivery of safety training to contestants. The research objectives are to develop a Serious Game for Fall Prevention Training that considers the following:

I. Incorporates relevant safety training content;1 The scope of the safety training content in the Serious Game is limited to the Fall Prevention Training Guide published by the Occupational Safety and Health Administration (OSHA, 2020).

II. Implements the Serious Game in a Virtual Reality (VR) environment to increase its engagement and interaction qualities.

III. Validates the Serious Game by conducting a pilot study.

Development of Serious Game

A Serious Game development timeline is provided for the readers to highlight important processes and methods used. The technology used in the development of the Serious Game is discussed. A suitable Serious Game framework is selected through the literature review, which forms the basis for the game's development. The motivation to select the OSHA Fall Prevention Training Guide as safety training content for FallSafe is due to falls at construction sites being a top cause of injury and death. According to OSHA, the most frequently cited violated standard for the fiscal year 2019: the "fall protection." (29 CFR 1926.501). This violation has been on the top of OSHA's list for nine consecutive years. Six participants were selected, ranging from those having no safety experience to students who have undergone safety training. A pre-survey will help us collect information regarding safety training background and basic demographic information of the participants and their experience in playing games. The survey contains a follow-up survey and a User Engagement Scale (UES) consisting of 31 questions to be scored on a 5-point Likert scale. The purpose of the feedback survey and UES is to obtain feedback regarding the effective delivery of learning content and overall engagement provided (Figure 1).

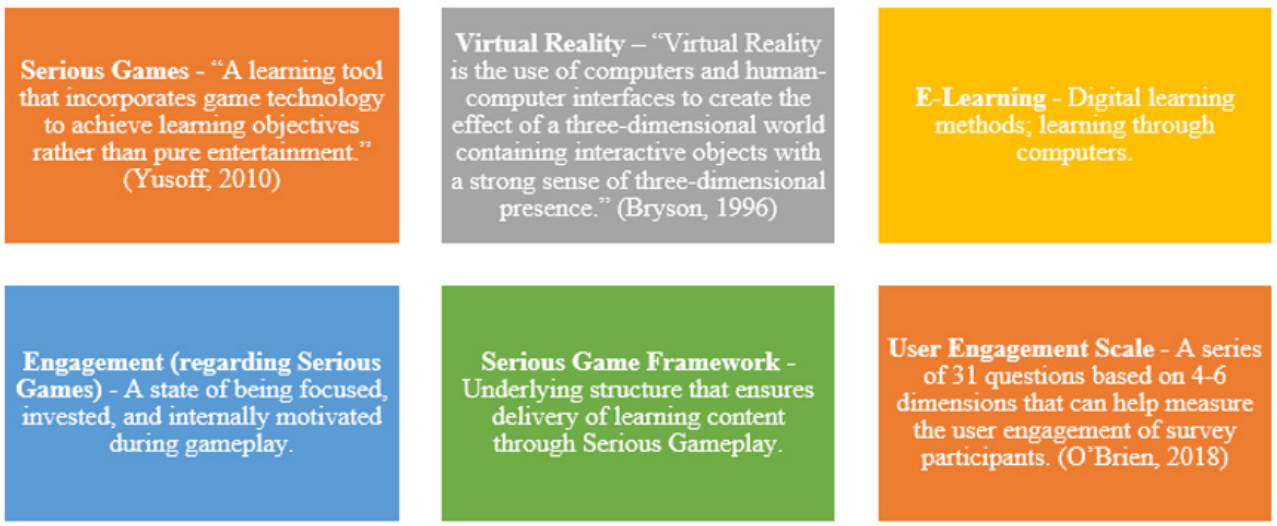

Figure 1: Terms and Actions in the FallSafe.

It is important to note that for this study, Serious Games specifically refers to Educare for games used with modern computer applications. While several definitions present similar concepts, the most specific and detailed definition provided by Bergeron B [1] guided this study. He defines a Serious Game as an interactive computer application, with or without an important hardware element, that has a challenging goal; is fun to play and/or engaging; incorporates some concept of scoring; imparts to the user a skill, knowledge, or attitude that can be applied in the real world.

Engagement in Games

Training-based Serious Games in the 1970s resulted from the idea that the current training and education methods at the time were demotivating, and Serious Games would provide greater interaction and engagement [2]. Garris et al. [3] describe the process of engagement for a player in a video game using an Input-process-Outcome game model. They state that if learning content is incorporated well within game attributes or characteristics, a game cycle is activated in which "users are engaged in repetitive play and continually return to the game activity over time". The cycle engages and induces self-motivation in the player, which leads to an understanding of the learning content.

Gee [4] describes motivation as the most critical factor that facilitates learning. According to them, good video games create an environment for people to recreate and learn simultaneously, and players absorb themselves in the game environment, something that traditional tools cannot achieve. When players deeply engage in an activity, they are in a state of "flow".

Bente and Breuer [5] stress the importance of entertainment in games designed for learning and report that we should always access entertainment within a game when the effectiveness of learning through games is discussed. Entertainment influences player involvement as described by Antonova and Ekambaram [6]: games create interest by using drama, storyline, humor, and characters to create a memorable learning environment. These factors add to player engagement and facilitate them to recall moments and information they learn in the game environment with ease. Dickey [7] discusses various strategies that are used in

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video games to engage the player:

a. Player positioning within the game: Games use the First-Person Perspective [7] in which the player experiences the game environment from the viewpoint of the player's virtual character.

b. Narrative: The use of story within the game to create engagement

c. Interactive choice: Use of characters, game environment, and player choices within the game to create engagement.

The first-person perspective is enhanced in FallSafe by using Virtual Reality. Players can look in any direction as in real life and view the construction site and surrounding land and city. They can interact with objects in the environment, such as grasping an item, with hands they can see and move with two hand controllers. FallSafe proceeds through a narrative, moving from task to task while delivering training. The use of characters includes the first-person player as a construction safety intern interacting with the site safety coordinator. All these components were added to enhance engagement in the game and, therefore, recall of safety contents [8-13].

Training Tool Development

FallSafe is a Serious Game aimed at educating the player about the fatal hazards associated with falls in construction. FallSafe is playable in VR only using the headset and controller combination. It is designed with the learning objectives of OSHA Fall Prevention Training:

i. The player must first select the appropriate Personal Protection Equipment for the situation

ii. Give the player an introduction to fall hazards in construction (number of fatal injuries due to falls, most violated standard for the last nine consecutive years, mention the basic fall protection systems used in construction)

iii. Educate the player about the unsafe practices related to ladder use by presenting them with a case study of a fatal injury due to a fall from a ladder, followed by safe and unsafe practices for ladder use on a construction site

iv. Explore a 3D model setup of a residential construction site and look for workers engaged in unsafe practices. After the player notices an unsafe practice, they can take note of it and answer a multiple-choice question related to that hazard. There are four scenarios (hazardous) and four sets of questions.

v. After the player has observed all the unsafe practices, they complete a comprehensive post-test (consisting of multiple-choice questions) to enhance knowledge retention.

To achieve learning objectives, FallSafe uses a storyline-based approach and is divided into four modules:

i. Tutorial Module (how to play the game)

ii. Introduction to fall hazards & ladder safety

iii. Observation of unsafe practices

iv. Reinforcing Posttest/Multiple Choice Questions (to reinforce the information gained in the last two modules)

The game storyline consists of the player, a newly recruited safety intern, on the first day of their internship. A 3D model of a construction site is implemented in the game world prototype, which includes the following components used to add a sense of realism to the game:

i. 3D models of animated characters (safety coordinator, workers, superintendents) with voicing that the player can interact with

ii. 3D models of construction equipment, under-construction residential housing, on-site office trailers

iii. A tutorial screen that greets the player on game start and provides them with instructions on how to progress in the game

iv. A safety briefing screen provides information regarding Case studies of fatalities due to falls, line diagrams depicting fall hazards, quantitative data for fatalities due to falls, and best practices to adopt for fall protection in ladder safety

v. The player navigates through the game, observing four unsafe practices, then answering a series of multiple-choice questions

vi. The game concludes at the briefing screen, where a comprehensive multiple-choice exam is given.

The game world is modeled around an active construction site consisting of residential housing. The wood framing is currently under construction, and there are workers throughout the site. The game starts with the player (safety intern) present on the sidewalk outside the construction site. On game runtime, the player is given specific instructions through the tutorial screen to get them familiarized with the game controls and moves through character interactions, briefing screens, and tasks to progress through the game. A tracking system is used to record tasks the player must complete for the game storyline to progress. The tracking system consists of:

a. A script using the Breadth-first search (BFS) algorithm to traverse the task list in any order defined by the game developer. This provides the player with a list of tasks and the order in which they need to be completed to progress in the game. For example, the player needs to approach the phone first and then enter the construction site.

b. Audio - Visual aids and sensory feedback: A covering red cylinder directs the player to the location of the next task to be completed. The player moves towards the red cylinder to

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progress through the game. Only one cylinder is visible at a time due to the game's linear nature. The player must move within close range of the red cylinder to trigger the box collider associated with the current task.

A sound will play when the cylinder changes color from red to green, and the handheld controllers will vibrate (haptic feedback) to inform the player when they complete a task. Audio - Visual aids and sensory feedback supplement player interaction with the game world making the gameplay engaging. When the player completes four tasks, they are instructed to navigate back to the briefing screen to take a comprehensive test to complete the game.

Pilot Testing

Play testing is conducted to enhance user experience, game play and confirm that intended learning outcomes are met. This chapter describes the pilot testing of FallSafe, which is conducted to validate the Serious Game. Six students from Michigan State University's Construction Management graduate program with varying levels of construction safety knowledge volunteered to pilot-test the game and filled out a feedback survey; the entire process takes about one hour. This study is approved by Michigan State University IRB, and participants receive a research briefing and sign their respective consent forms before commencing the study. Instruction for game setup and play is given to the participants. Participants are instructed to play the game for 30 minutes, then fill out the feedback survey. The survey asked three open-ended questions for feedback on FallSafe. The feedback and suggestions are noted and will be used to create enhanced versions of FallSafe in the future. The questions posed to participants:

What are the best features of FallSafe? Why?

One participant responded stating that the tutorial screen "provided clear instruction throughout the game," and another participant noted that the red/green "capsule system used for navigation was helpful," assisting participants in navigating through the game as intended. "The storyline of the game" is a positive response received from a participant regarding engagement and realism. "The briefing screen (that provided safety contents and fall data) was a good feature" is another positive comment from a participant.

What are your least favorite features of FallSafe? Why?

"In the game, character movement could have been smoother" is one response from a participant. Another participant notes, "There could be more (in-game) character interactions to help the game feel more realistic." Character animation is also a least favorite feature, with multiple participants pointing out that animation of the 3D characters could be more realistic.

What are your suggestions for improving FallSafe?

One participant suggests adding both safe and hazardous scenarios to enhance realism. "There could be a map attached to the tutorial screen" is a great suggestion provided that would enhance in-game navigation, as many video games have this feature. "Add more modules" is suggested by multiple participants. One participant suggested adding both more modules and more unsafe practices to add complexity to the game. Since engagement is the primary concern for validating FallSafe, questions asked participants to score 31 questions using the User Engagement Scale (UES) to measure engagement provided by FallSafe.

User engagement (UE) is defined as "a quality of user experience characterized by the depth of an actor's cognitive, temporal, affective, and behavioral investment when interacting with a digital system." Engagement is about more than just attention or interaction; it is a state of complete involvement in something. The UES is found to be an effective tool for measuring engagement in a variety of digital media, including Serious Games, and asks a series of questions based on six dimensions in Table 1.

Table 1: Six Dimensions in Serious Games.

FA	Focused attention, feeling absorbed in the interaction, and losing track of time (7 items).
PU	Perceived usability, negative affect experienced because of the interaction, and the degree of control and effort expended (8 items).
AE	Aesthetic appeal., the attractiveness and visual appeal of the interface. These questions are straightforward and ask about visual attraction to the game.
EN	Endurability, the overall success of the interaction, and users' willingness to recommend an application to others or engage with it in the future.
NO	Novelty, curiosity, and interest in the interactive task (3 items). "I continued to use this game out of curiosity" was one of our questions, and if it is scored higher.
FI	Felt involvement, the sense of being "drawn in" and having fun (3 items). These questions reflect the enjoyment of the game by the participant.

Conclusion

FallSafe provides a promising experience that is engaging and interactive. Improvements can be made to further enhance its experience, as is evident from participant feedback. Results prove that FallSafe is a refreshing method of delivering construction safety content, and players are absorbed in the experience, which motivates and intrigues their learning interest in construction safety. To address the shortcomings of traditional safety training, the use of an engaging and interactive medium to deliver construction safety training is called for. The use of Virtual Reality technology, first-person perspective, and narrative storyline adds a layer of realism to FallSafe that had not previously been

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demonstrated in construction safety training. The combined use of Serious Games with Virtual Reality helped create a realistic story-based training module that invoked interest and learning desire within the participants.

The Unity 3D game engine proves to be a great platform for developing FallSafe due to its seamless support for major Virtual Reality headsets available on the market. The Oculus Rift S VR headset and hand controls allow the player to use typical hand movements in the game and look in any direction, contributing to realism and an enhanced first-person perspective. The XR module support by Unity 3D makes Virtual Reality integration convenient and saved time on development. The DPE framework enables FallSafe to meet its learning requirements and the Serious Game is enhanced by playtesting the game prototype several times. Finally, pilot testing of the game is conducted to validate FallSafe. Participant feedback after playing FallSafe was overall positive, with players reporting FallSafe as a viable tool for teaching construction safety training. Participants reported clear instructions and an enjoyable storyline, with suggestions for enhanced graphics and a greater variety of modules and character interactions.

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