Serious Games for the Learning and Practices of Hazard Recognition: Understanding the Design Complexity for 3D Construction Site Modeling

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ABSTRACT

Among the various construction safety and health (S&H) training methods, 3D digital game-based learning is believed to have a great potential. This method can combine various educational strategies to engage learners that have grown up with computer gaming. To this end, an increasing number of 3D serious games have been developed for the learning of construction S&H. However, developing a virtual construction-site simulation for serious gaming is a tedious process. Little has been done to understand the simulation parameters that should be controlled in order to adequately represent the dynamics of a construction site and, as a result, to influence student learning. Therefore, the purpose of this study is to understand and prioritize the 3D construction-site simulation parameters for learning hazard recognition. In the paper, the researchers reported their findings on the S&H game design framework as an initial step to identify how simulation parameters such as texture, lighting, and animation could align with game contents and positively affect student learning. A future experiment for validating each parameter was also introduced. The researchers expect that the final research outcomes will enable construction education stakeholders to better understand and manage the design complexity of 3D construction-site modeling for S&H serious games.

INTRODUCTION

One effective way to promote the awareness of potential construction safety and health (S&H) hazards through training and education is by exposing learners to the cause of accidents/hazards and the resulting incidents. However, reproducing hazardous situations and accidental outcomes in the real world is challenging, due to the involved risks, expenses, and time, etc. (Susi et al. 2007). In this regard, game and virtual environment (VE) based S&H training/learning is advantageous in that it shows students hazardous factors, demonstrates accidents through exploration, and offers the long-term benefit of retention (Dickinson et al. 2011; van Wyk and de Villiers 2009). In spite of these benefits, there are several barriers to the utilization and implementation of a construction S&H serious game in a classroom environment. First of all, many construction management and engineering educators might not be familiar with the highly complex serious game design and development process. Additionally, the use of three-dimensional (3D) game engine technology is a challenging process that requires skills in computer language, 3D modeling, and computer graphics (Van Rosmalen et al. 2011). Kelle et al. (2011) pointed out that the challenges in introducing a serious game, as a tool for teaching and learning, include labor and cost concerns as well as design complexity. Unlike games which are intended for pure entertainment, the method and process of game production need to be simpler so that serious games can be an adaptable for teachers (Van Rosmalen et al. 2011). Several serious game researchers have questioned the myth that simulated virtual environments should be extremely realistic and emulate the exact physical aspects of the real world (Herrington et al. 2007; Westera et al. 2008).

In the game-based learning arena of construction S&H, many educators (Lin et al. 2011; Guo et al. 2012; Li et al. 2012; Addison et al. 2013; Chen et al 2013) have designed and developed several serious games. However, a clear understanding of the framework of game design framework and the opportunities exhibited by the framework for reducing design complexity have not been critically addressed. Ultimately, we wish to promote VE-based S&H training/learning by removing barriers introduced by unnecessary design complexity. This paper will present our approach to understanding and developing a framework for game design, and discuss our strategies for prioritizing the representational parameters of the game design.

SERIOUS GAME FRAMEWORK AND LEARNING PERFORMANCE BY DIGITAL GAME BASED LEARNING

In order to control the game design complexity, it is necessary to understand the framework for game design. Westera et al. (2008) introduced a game design framework composed of practical, conceptual, and technical levels. Each of these levels addresses the game design complexity from a pedagogical perspective. From these three levels, we focused our investigation on the practical level concerning feedback (the process of the game rating and scoring mechanism), game structure (the complexity of numerous decision trees within the game), and game representation. Much thinking and effort on feedback and game structure is necessary in order to create a serious game that contains authentic educational content and scenarios. However, game representation could provide an opportunity to reduce game design complexity. This is because unlike entertainment games, outstanding graphic descriptions and rich user experiences are not the ultimate goal of a serious game (Michael and Chen 2005).

While exploring the opportunity to reduce the serious game design complexity, it is also important to keep in mind that such reduction cannot compromise the intended learning. Previous research has indicated that learner motivation is the influential factor behind successful game-based learning (Prensky 2001). Such motivation comes from the learning engagement and realism facilitated by educational games and virtual reality (Tashiro and Dunlap 2007). Learning engagement depends on authentic, functional, and credible game contents (Herrington et al. 2007; Westera et al. 2008). Realism depends on how the real world is expressed through authentic graphical representation (Chalmers and Debattista 2009).

When attempting to maximize the educational effect of a serious game, past literature has placed a higher emphasis on the game's learning engagement than on its realism (Burke et al. 2011). After all when designing a serious game, an authentic representation has less impact than an authentic content upon learning motivation (Westera et al. 2008). Authentic content related aspects improve a learner's educational motivation as well as learning performance (Alexander et al. 2005; Herrington et al. 2007; Westera et al. 2008). Accordingly, when limited time and budget are available for game development, effort that raises the credibility of game contents should receive a much higher priority than that implements representational feature irrelevant with intended learning purposes. Among the various construction S&H serious game studies, little has been reported to understand how representational features really matter to game content.

METHODOLOGY

Based on the literature reviewed in the previous section, educators should maximize their effort and time on designing highly authentic contents and on providing properly situated role-play and problem solving tasks to student. On the other hand, during serious game development, representational features need be to be prioritized, in order to reduce design complexity but still guarantee a high-level learning experience. Since many concepts and design elements of serious games have been discussed in the previous section, we developed a diagram to summarize (*Figure 1*) how the practical level of a game development process by Westera et al. (2008), i.e. game structure, feedback and game representation, is connected to the eventual learning performances at the end. A clear understanding on the connection between the educational content (Item 5, *Figure 1*) and the design parameters (Item 6, *Figure 1*), i.e. finding parameters which are highly involved with game contents, will greatly inform an effective and efficient game development process. Design representation often calls for a vast investment of time and cost, which creates barriers for the construction educator-researchers who wish to develop serious games for pedagogical purposes. While a fun and immersive game supported by authentic graphic sceneries increases a learner's motivation, an engaging game driven by the learning contents has a far more significant impact upon the learner's motivation. Hence, the efforts for enhancing representational realism alone in virtual environments does not guarantee the effectiveness of student learning outcomes driven by learner's motivation.

As a result, to minimize game design complexity with limited time and cost with maximum learning outcomes, it is important to prioritize design parameters (Item 6, *Figure 1*) which help educators identify the ones that can situate construction activities, means, and methods as well as their related S&H hazards in the game scenarios. With the proposed research, we can verify for example if a rusty metal shore can be recognized in a virtual environment without a realistic texture attached, or if a puddle of water accumulated on site presenting electrical hazards for the nearby tools can be recognized without a reflective texture to make sense in the eyes of a human learner. Since the goal of our game is enhancing student's ability to recognize S&H hazards on construction sites, recognizing virtual objects and simulated situations along with educational contents crucially influences student's learning performance. To this end, an additional step was added to the framework (Item 20, *Figure 1*), aiming to guide serious game educators gauging the allocation of their design efforts. This step will also (1) bring more attention to calibrating the game contents, and (2) help minimize the representational design complexity with a concentration on only the parameters that matter for construction S&H training.

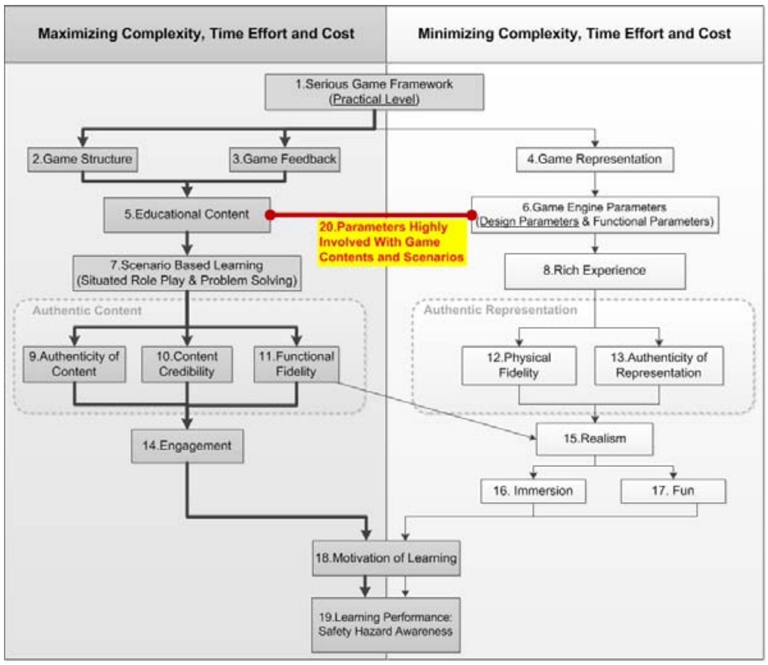

Figure 1. Serious Game Framework and Factors Associated with Learning Performance.

Following our efforts to identify the serious game framework and factors associated with learning performance, we propose a workflow to develop a S&H serious game. As an example, *Figure 2* illustrates the modeling decisions for a wooden pavilion construction project and its S&H hazards in a 3D serious gaming environment. It demonstrates the logical sequence of determining involved activities/means/methods, identifying related S&H hazards, and designing the functional and representational parameters. The educational goal of the pavilion project S&H serious game is for students to acquire knowledge about the perceived activity risks and applicable safety precautions that prevent or reduce the hazards. This process will be used by the researchers to verify the suggested step (Item 20, *Figure 1*), when modeling the example pavilion project. The educational goal will be used as the evaluation criteria during the validation of the research.

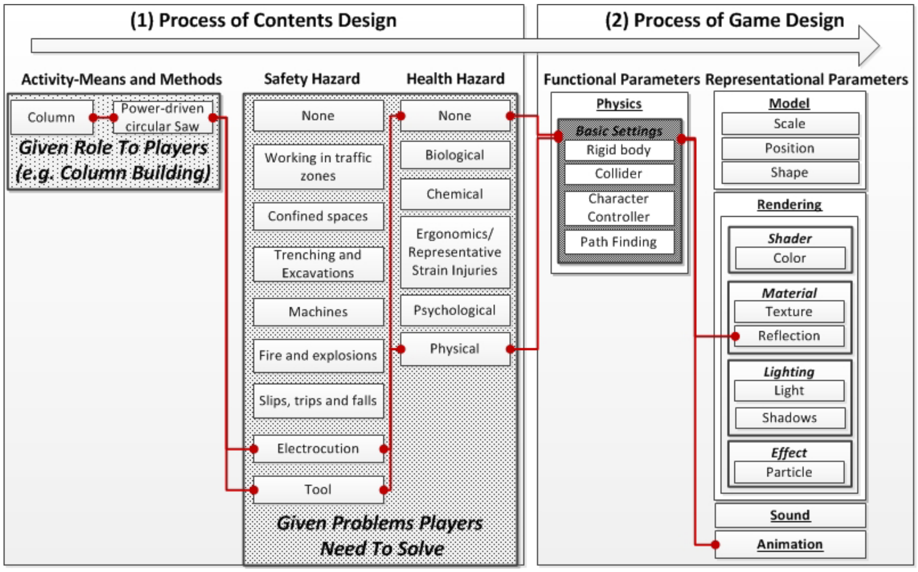

Figure 2. Decision Making Process of 3D Serious Game Design- Column Building Activity Example.

The Process of Contents Design. As discussed, a prerequisite in terms of game-design framework is to appropriately plan an educational game's contents. Since 3D model objects are related to the intended contexts, they are critical elements that can present the causes of construction site safety hazards and are not considered just one of representational parameters. For instance, when machine excavation is chosen as a method for footing activity, the most common risk is "struck-by". In order to demonstrate the idea of "struck-by", 3D objects in the virtual world for the worker avatar, machine excavator, adjacent structures, etc. are essential. With the same logic, four contexts of learning (*Table 1*) can be defined for the pavilion project during the process of contents design. The contexts help inform what 3D objects are needed and in what arrangement.

The Process of Game Design. The process of game design involves the determination of the functional parameters (e.g. object physics) and the representational parameters (e.g. model scale). While model related representational parameters like scale, position, and shape are usually important in order for the model to make sense, it is unclear which remaining parameters truly impact the learning content. For example, Context 3 (*Table 1*) involves using an electrical tool and dragging the tool cord through a water puddle in the field. To illustrate a realistic water puddle, reflection from sunlight and surrounding objects has to be placed on the water puddle. However, in order to create such a realistic expression, additional game development efforts are necessary. If a realistic expression of the water surface reflection helps students recognize the existence of a wet area and as a result highlights the potential hazards (e.g. electrical shock), then "reflection" as a representational parameter is worth the attention. If the parameter does not contribute to the learning content, omitting the parameter will save cost and time.

Table 1. Game Contents Design Examples.

No.	Activity	Means and Methods	Safety Hazard	Health Hazard	Context
1	Site Logistics	None	Working in traffic zones, electrocution by overhead power line	None	The overhead power lines pass near the construction site, and the poles are installed in front of the south side of the site. Some vehicle traffic might be expected.
2	Footing	Machine excavation	Stuck by moving machinery	None	A machine excavator is operating near employees working on other tasks.
3	Column	Power-driven circular saw	Electrical shock by working at wet area	Physical (noise)	A worker is using a power-driven circular saw to prepare for installing column. The working station and equipment are in a water puddle.
4	Beam	Power-driven circular saw	Tool use without PPE	Physical (noise)	A worker using power-driven circular saw was not wearing proper personal protective equipment with serious noise from the tool.

CASE DEVELOPMENT FOR EXPERIMENT

For each learning context of the pavilion project, the researchers have selected one representational parameter for the experiment (*Table 2*). Each parameter was selected for its relevance in demonstrating the hazard, intended for the learning context. Basic game scenes for each context were built using the Unity 3D game engine. These game scenes have been identified (*Figure 3*) and will be used as the control group for the experiment. The process of furnishing advanced scenes to reflect the incorporation of representational parameters has been conducted to align with a given learning context/content for the construction of S&H education. The advanced scenes will be used as the test group and help validate the representational parameters that eventually contributed to the learning performance. The researchers foresee that the validated final research outcomes will enable construction education stakeholders to better understand and manage the design complexity, when encountering 3D construction S&H challenges.

Table 2. Connecting Potential Game Representational Parameters with Contents.

	Context 1	Context 2	Context 3	Context 4
Representational Parameter	Lighting (Shadow)	Animation (Excavator)	Reflection (Water)	Sound (Circular Saw)

Figure 3. The Game Scenes for the Control Group.

CONCLUSION AND FUTURE WORK

In a serious game, the authenticity of game contents is more important for improving student learning performance than the representational realism of the virtual world. Educator researchers adopting serious gaming for S&H training should focus on developing game contents with highly credible scenarios and align game design parameters such as animation, lighting, shadow, reflection etc., with the content. This paper presented a serious game framework and an operational process for developing construction S&H serious game. The paper also illustrated example game contexts defined for a pavilion project and their related representational design parameters. The presented game contexts and parameters will be verified in the near future to understand their effects on learning outcomes through actual testing and evaluation by students at the University of Washington. The experiment will involve control and test groups to venture through a series of hazard-recognition simulations. The game scores will be recorded during the game playing with post-survey and follow-up tests being conducted to assess students' learning outcomes.

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