Designing a Game for Occupational Health and Safety in the Construction Industry

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ABSTRACT
Safety in the construction industry is important because people continue to be injured on construction sites. To address this, the Australian construction industry and its regulator, the Office of the Australian Building and Construction Commissioner, have required that anyone who intends to work on a construction site must complete an Occupational Health and Safety (OH&S) construction induction process.

One complex section of the construction induction training deals with the identification of hazards and the management of hazards through controls to prevent workers from injury. There is a multitude of worksite hazards and many OH&S controls.

A key challenge for OH&S training is to engage learners. Serious Games are a promising vehicle to engage learners and enhance their retention of important concepts. This paper reports on the design decisions and the development of an informative and entertaining game, which is intended to motivate users to learn about workplace hazards. The game is also intended to help users retain their knowledge of workplace hazards and their management, and to assist with knowledge transfer into the real world.

Keywords
Serious Game, Occupational Health and Safety, Learning, Construction Industry, Hazard Identification.

1. INTRODUCTION
People in the construction industry continue to be hurt. In Australia, the construction industry represents 9% of the workforce, yet 11% of all serious workers’ compensation claims occur in construction and the industry has a fatality rate of more than twice the rate for “all industries” [1].

In an attempt to address this high injury rate, the industry and its regulator, the Office of the Australian Building and Construction Commissioner, have established a construction induction process also known as White Card Training. A National Code of Practice for Induction for Construction Work was developed in conjunction with the Australian Skills Council, which regulates Trade training. This training provides guidance about the common hazards on construction sites and their management and corresponds with the learning requirements of the Australian Certificate I in “Work safely in the construction industry” [2].

Anecdotal evidence indicated that students were often disengaged in the course, which raises questions about the effectiveness of the delivery format and retention after the training [3].

In this project we developed a game about hazard identification and the management of hazards through OH&S control measures. The game aims to address the issue of learner engagement in construction induction training and to increase the retention of what users learn. This paper describes the design decisions that were made to develop the game.

2. BACKGROUND
The total economic cost of work-related injury and disease is close to 6% of Australia’s GDP [1]. The vision of the past National Occupational Health & Safety (OH&S) Strategy 2002-2012 [4] and the new strategy 2012-2022 [5] is for Australian workplaces to be free from death, injury, and disease. Key priorities involve the reduction of high likelihood/consequence risks, and to improve the OH&S capability of all Australian business operators and employees. Construction is regarded as a priority industry due to its injury and fatality rate [5].

The national strategy 2012-2022 suggests that in order to improve Work Health and Safety Capabilities, work health and safety skills development should be appropriately and effectively integrated into relevant education and training programs [5]. Since human lives depend upon the performance of trainees [6], the need for effective training has been identified to prevent avoidable injuries in the future [7]. A critical success factor, however that influences the effectiveness and appropriateness of training, is the engagement of learners.
Technology facilitated training is increasingly recognised by corporate organisations [8] as an important method and less an obligatory fulfilment of a mere legal requirement [9]. Despite market growth, however, the quality of many eLearning environments is still lacking. For example, a web-based survey conducted amongst European training professionals [10] showed that 61% of respondents rated the overall quality of eLearning courses as “fair” or “poor”. In contrast, only 6% of the courses received the rating “good” or “excellent”.

Several previous studies support the motivational aspects of computer games. Research on game play in Australia by the Interaction Association of Australia and Bond University [11] found that nearly every Australian household had a device for playing electronic games. Participants in the study reported that the strength of electronic games is their ability to foster entertainment and relaxation. Motivation for playing games included: relaxing; having fun; passing the time; challenge; social aspects; excitement; and fantasy. Since games have the potential to induce what Csikszentmihalyi [12] defines as ‘flow’, in which players become so immersed and engaged that time and place become unimportant, there has been increasing interest in using games within educational contexts. The current generation of students has grown up playing computer games [13].

Active learning contributes to ‘deep’ rather than ‘surface’ learning. Deep learning manifests as the development of real, lasting, personal understanding, evident for example through the ability to predict; whereas surface learning can involve rote learning of facts, with little or no meaningful or lasting learning evident [14-17].

A study based on 164 students enrolled in a variety of courses leading to careers in the construction industry has shown that students tend to be surface learners with a lack of motivation to complete a course of study, and with limited individual responsibility for their learning. The same study has also indicated that the students prefer activity-based classroom teaching in a peer learning environment, with a high degree of instructor monitoring to check on their progress. The students also prefer structured course content and assignments that are presented graphically with little text [18].

From an educational point of view, Prensky [13] suggests that electronic games are particularly useful within contexts where learning may be perceived as complex or boring. Gee [19] supports this view and believes that games are designed in a way that triggers a deep motivation for learning. The vast majority of electronic games provide a highly structured environment with tutorials for players that are new to the game. Such games often break down complex tasks into smaller more manageable tasks, which cater for the individual pace of the player and give immediate and continuous feedback along the way [19].

Dalgarno and Davies [20] report that learners perceived Serious Games to have an advantage over a real investigation for fire safety training, because they were able to explore multiple outcomes for particular actions as opposed to being forced to choose only one ‘final’ action.

Moreover, electronic games often require players to formulate hypotheses, experiment with the content and evaluate the outcome, which is a cycle of activities that are closely related to the learning process defined as ‘experiential learning’ [21]. This approach has been linked with better learning outcomes [19, 22].

Similarly, a contemporary (learner-centred) approach is associated with motivation and retention of material [23]. In this approach, underpinned by a constructivist epistemology, learners are engaged in active and interactive learning activities and construct their own knowledge and understanding, rather than being passive ‘receivers’ of information [24]. Constructionism [25] extends the concept of constructionism, because learning and the construction of knowledge is embedded in the construction of an artefact – simply put, ‘learning-by-making’. Chan [26] reports the use of constructionist learning principles through a number of serious games that aim to teach children about environmental concepts and this success can be extrapolated for games designed to support adult learning.

3. GAME DESIGN

The game under discussion in this paper is designed to address the common hazards encountered on a construction site. It is designed as an activity that supports the learning and teaching involved in the construction induction training. The game follows a constructivist approach that supports players to construct their own knowledge about the layered control measures. Different solutions are provided for the user to choose from, with immediate feedback given. The game provides opportunities for the player to manage hazards via OH&S controls and thus indirectly impact on the overall productivity of the worksite. The game addresses some of the elements and performance criteria outlined in “CPCCOHS1001A Work safely in the construction industry” [2] unit including:

- Identify construction hazards and control measures
- Identify OHS communication and reporting processes
- Identify OHS incident response procedures

Some elements of the training: “Identify OHS legislative requirements” and most of “Identify OHS incident response procedures” were not construed as being conducive to game play and are not part of the game.

The game addresses the construction students’ preference for activity based teaching and the desire for assignments that are presented graphically with little text.

3.1 Gameplay

The game takes place in the construction site of a large multi-storey tower. Each level shows a segment of the tower as illustrated in Figure 1.
Animated Non Player Character (NPC) workers work on the construction site. To address element two in the “Work safely in the construction industry” unit i.e. “Identify construction hazards and control measures”, the NPC workers each face a different hazard that needs to be managed before the worker can do their work. The NPC workers are unable to manage the hazards by themselves and are injured when exposed to the hazard. It is the task of the player to identify and manage the hazards on the worksite via a hazard control user interface before NPC workers become injured.

Following the constructivist approach, the player can experiment with all the controls and freely apply them to either the NPC worker or the hazard. Immediate and supportive feedback is provided whenever a control is applied. The player is visually rewarded with the completion of a section of the building if the correct control is applied. Similarly, animations in line with the cartoon inspired ‘look and feel’ of the game are triggered, showing the consequences if the NPC worker is exposed to the hazard or if an inadequate control is applied.

The learning objectives are distributed over a number of levels. Each level contains a small number of hazards that the player needs to manage. Similar to the NPC characters in the popular game Lemmings, the NPC workers in this game walk blindly into a hazard and are being injured as a consequence of the exposure to the hazard. Every injury to an NPC worker depletes the work rate of the construction site, which creates indirect time pressure for the player. The indirect time pressure provides an additional motivation for players to act quickly as NPC workers continue to be injured until the hazard is resolved. The work rate for every level in the game is recorded and becomes a factor that determines game success at the end of the game. This reinforces the relationship between hazard control and productivity.

### 3.2 Technology

The game was developed in Unity 3D for the iPad 2 to facilitate the game’s distribution via the Internet through the Apple AppStore. The touch sensitive interface also provides a more hands-on learning experience, which was reported in one study as being enjoyed by almost all construction students [18]. From a game development perspective, the choice of the game platform clearly defined the resolution, detail, performance and interaction paradigm for the game. Although designed for the iPad 2, the game is also playable on PC and Mac computers with a mouse.

### 3.3 Hazards and Control Logic

The construction induction training covers more than 50 common hazards and 30 OH&S control measures. In the game, the player can experiment with 38 hazards and apply every available OH&S control. Depending on the situation, controls can have a positive, neutral or even negative effect on the overall productivity of the construction site.

To resolve the complexity of hazards, controls and the effectiveness of the control, we developed an extensive hazard and control matrix. An excerpt of this matrix is illustrated in Figure 2. The columns designate the controls, and the rows designate the hazards. The intersection of the columns (controls) and the rows (hazards) shows the effectiveness of the control measures. Depending on the hazard and the situation, a control measure can be recommended (cell highlighted in green), adequate (yellow cell), neutral (grey cell) or negative (red cell). The cells themselves contain descriptions of the animations that are triggered for the various scenarios.

The hazard control matrix formed the basis of the game design document and subsequently the development of the game.

### 3.4 Managing Hazards

Based on the competency “Work safely in the construction industry” [2] the 30 measures for controlling risk in the game are grouped in the following hierarchy: elimination; isolation; engineering controls; administrative controls; personal protective equipment; and fire extinguishers. While a traditional hierarchy of controls would also include substitution and more administrative controls as additional level in the hierarchy, these were difficult to convey in this game structure. OH&S documentation, e.g. Material Safety Data Sheets, are used as Help systems and described in more detail in Section 3.5.

To support the preference of the construction students for graphical presentations and to avoid text [18], the hierarchy of controls is symbolised by a set of six buttons with icons for every hierarchy and is centred at the bottom of the screen. The hierarchy of controls is illustrated in Figure 3.

![Image](image318x303-556x322)

**Figure 3: Hierarchy of Controls**

When the player taps on one of the hierarchy buttons, a tab slides out to the right and reveals the individual controls. The colour scheme for each hierarchy of controls is related to the colours used in real-world construction site signs and the colours used in the courseware book [27], which helps to integrate the game with the classroom content. For example, the colour red is used for the Fire Extinguisher’s hierarchy of controls; blue for Personal Protective Equipment, etc. Figure 4 shows the expanded view of the Fire Extinguisher controls as an illustration of this.

![Image](image318x466-556x522)

**Figure 4: Fire Extinguisher Controls**

To support learning, the player can trigger information about the hierarchy or the individual controls by holding down a finger over the respective button (hierarchy or control). For hierarchy buttons an information box appears. Control buttons show an enlarged icon of the control object itself, so that the player can recognise the control measure in the real world. The control information also contains a text box that provides essential information in textual form. Figure 5 shows a screenshot of the game with an enlarged fire extinguisher object, and explanatory text about its use in an oval shape at the top of the screen.

The information is a reference for the player and the information disappears as soon as the player lifts the finger from the touch interface.
Some hazards are managed by applying the control to the worker, and others can be managed by applying the control directly onto the hazard. To apply a control, the player needs to tap on the control button, which triggers a small image of the control as a cursor. The control can be applied to the worker / hazard, either via a finger swipe motion or by tapping with the finger onto the worker / hazard. Similar to other ‘drag and drop’ games, a highlight appears around the worker / hazard which provides the player with a signal that the control can be applied. If the player tries to apply the control to an area that is not occupied by a worker / hazard, the control snaps back to the menu. The player can reapply the control again as long as the hierarchy or control is not changed. Controls that are applied onto an NPC worker can be changed without penalty, as long as the NPC worker has not been exposed to the hazard. Controls that are applied directly onto a hazard are actioned immediately.

Replicating the real world, the suitability of a control depends on the situation and can trigger a number of different outcomes. In certain situations, a control can be the recommended choice, which results in the effective management of the hazard. In other cases, the same control can have negative consequences for the worker or the work site. For example, the control ‘barrier’ can be used to successfully manage a falling hazard caused by an open hole in the ground. While the same control can also be used to stop the hapless NPC workers from walking into an open fire, it cannot be used to manage the fire hazard and prevent the fire from spreading.

3.5 Help Systems

The Safe Work Method Statements (SWMS) and Material Safety Data Sheets (MSDS) are document types that are requirements for Australian work sites in the real world.

The Safe Work Method Statements (SWMS) assist construction workers to consider how certain activities can be carried out safely. In the game, the SWMS contains hints on how to manage the hazards. For example, one of the hazards might be manual lifting. The SWMS contains all the steps required in order to lift a heavy load correctly, even though the solution in the game is much simpler. Through this, the SWMS explains the real-world method required to complete actions depicted in the game.

Figure 6 shows the SWMS in the game.

The MSDS provides workers and emergency personnel with information for handling or working with hazardous substances in a safe manner. To provide the player with a similar kind of support, but without overwhelming the player with too much textual information, the MSDS in the game (Figure 7) only contains substances on the current level and contains information such as the substance’s description, safety precautions, suggested personal protective equipment, and ways to manage the hazard. The description is accompanied by an image of the substance, so that it can be recognised in the game and in the real world.

3.6 Incident Reports

If a construction worker encounters a hazard in the real world, the worker must report the hazard via an incident report form. To reinforce the concept of reporting in the game but to keep the game moving, a report button appears once the player has managed all the hazards in the game level. When the player presses the report button, all the hazards from that level appear on individual incident report forms. The incident report forms in the game are illustrated in Figure 8.
to the unsolved hazards to motivate the player to action. This continues indefinitely and only stops once the player applies a correct solution to a hazard and therefore increases the productivity of the worksite. When the productivity bar reaches its upper limit, the bar glows in brighter colours.

3.8 Feedback for the player

The game provides the player with a range of positive and negative feedback for any action they take. The feedback system, however, is heavily weighted towards rewarding the player for correct actions with a multitude of visual effects. As Jesse Shell says in “The Art of Game Design”: “Aesthetic pleasure is no small thing. If your game is full of beautiful artwork, then every new thing that the player gets to see is a reward in itself” [28], page 347.

3.8.1 Positive feedback

As mentioned, when the player successfully manages a hazard with a recommended or adequate control, the player is rewarded with immediate positive feedback in the form of an animation that shows an increase in productivity and the completion of a part of the building. This feedback creates a link between safe work practices and productivity and progress. Once this has occurred, an animation is shown of the next floor being constructed.

3.8.2 Negative feedback

Learning to identify and manage hazards is important. However, this game also allows the player to safely explore the consequences of their actions and learn why some controls are more appropriate than others. The application of an inadequate control to a hazard can have two possible forms of response: neutral and negative. A neutral response does not resolve the hazard or have a negative impact on the productivity of the worksite, but it does trigger a humorous animation that temporarily portrays the consequences of the player’s choice.

A negative response shows the consequences to the NPC worker and the work site in an animation that takes artistic license and has entertainment value. These animations, although representing a penalty for applying the wrong control, encourage the player to experiment and discover these consequences accompanied by immediate feedback. The application of an inadequate control also has a negative effect on the productivity of the worksite. As a consequence of this action, the overall productivity of the game level is decreased in the productivity indicator.

3.9 Progression to the end of the game

The tower building consists of six floors, each with up to three playable levels. Each level deals with up to four hazards. When all the hazards on a level are resolved and the player has completed the reporting screen the camera moves and rotates around the building to a new face in a corkscrew motion. As more and more floors of the tower are completed, the building becomes taller, which provides the player with a sense of progression.

When the player completes the final floor of the building, the player submits their final incident reports. At this point, the player has reached the end of the game, which culminates in an animation showing a flag on top of the building followed by fireworks.

4. CONCLUSION

We developed a Serious Game for construction industry students. This game is about hazard identification, management via a hierarchy of OH&

S controls, and the relationship between hazard control and productivity. The game is designed as an activity to support the learning and teaching of construction safety induction.

3.7 Productivity

In the real world, many factors determine the timely completion of a building. However, workplace safety greatly influences the productivity of workers on a construction site. The game tries to capture this aspect with the productivity indicator on the left side of the screen. The indicator illustrated in Figure 9, shows a bar with colours ranging from red to green.

Figure 8: Incident Report Cards

At this stage, the player can review the hazards encountered and obtain feedback about the adequacy of the applied control. When the last card is sent to the supervisor, the game automatically continues to the next level.

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It addresses the construction student’s need for activity-based classroom teaching and highly structured course content that is presented graphically without excessive text [18].

Serious Games lend themselves to providing players with choices to create their own learning pathways, providing cognitive flexibility [29] and a more adaptive approach to learning, addressing a variety of learning styles [30].

This game supports players to build their own understanding about layered controls, by offering different solutions and providing opportunities to resolve conflicting priorities as observed by Dalgarno and Davies [20].

The game is also based on well understood game mechanics such as the progression dynamic [31] and supportive feedback loop [32]. This maintains the ‘flow’ of the game for the player.

To increase the exposure to the most important learning outcomes, the game has a larger number of hazards that addresses the statistically most common injuries, such as slips, trips and falls.

At the time of writing, the game is in its final phases of development. Subsequent user testing will provide data that will allow us to assess the engagement of students with the OH&S content, and retention of the content for transferring the learning to real-world situations.

If game playing proves to be a successful learning tool for OH&S in construction, the concept and development process identified in this research will be generalized to support the development of educational OH&S games in other programs.

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6. REFERENCES


