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A Case Study on the Use of SafeSim Investigation Simulation Game to Improve Incident Investigation Education

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Abstract

Effective incident investigation is an important element of a workplace safety and health (WSH) management system. However, learning incident investigation requires an authentic context, which is difficult to create in an Institute of Higher Learning (IHL). An educational digital simulation games (DSG) can provide an authentic experience to undergraduate students to learn incident investigation skills. Therefore, the aim of the study is to evaluate the difficulties, advantages and disadvantages of developing and deploying a DSG for teaching incident investigation in an IHL to improve the use of simulation games in WSH education. A prototype three-dimensional multiplayer DSG called SafeSim Investigation was developed to provide an authentic learning platform for Project and Facilities Management (PFM) students. The game is structured in two parts where in the first part, students role-play as a team of three incident investigators. Students are required to collect evidence in the virtual site which is guided by an incident analysis technique taught in lectures. By interacting with non-player characters, collecting objects and analysing documents will help students to unlock information about the incident. Students also must respond to quizzes within the game and receive immediate feedback for their responses. In the second part of the game, students are to recommend appropriate actions to improve WSH of the site based on their findings. At the end of the session, the system will calculate the students' scores and students can review their performance. Both practitioners and students provided positive feedback during the study, but they also provided numerous recommendations for improvement.

Keywords: accident causation theory, authentic learning, construction health and safety, incident investigation, safety training, simulation game, workplace safety and health

Introduction

The construction industry exhibits significant workplace safety and health (WSH) risk as it remains the top contributor for workplace accidents and fatalities around the world. The United States reported an increase in fatality cases from 971 in 2017 to 1,008 in 2018 (Bureau of Labor Statistics, 2019). In Singapore, the Ministry of Manpower (2019) reported that the construction industry is the main contributor for workplace fatalities in Singapore in the same year and accounts for a fatality rate of 1.6 per 100,000 workers. It is crucial for workers to identify and understand the root causes of an incident to prevent similar occurrences in the future. Therefore, an effective incident investigation is an important element of a WSH management system as it helps to determine the causes of an incident and facilitates improvement of the WSH management system.

The complexity of the dynamic and unpredictable conditions in the construction industry makes it difficult for inexperienced personnel to understand how to conduct investigation in the industry. Furthermore, it was suggested that the pedagogical method adopted in construction safety and health training and education were inadequate (Bell et al., 2001; Dipiro, 2009). There it is especially challenging to teach incident investigation to undergraduates with no industry experience. Furthermore, learning incident investigation requires an authentic context, which is especially difficult to create in an Institute of Higher Learning (IHL). It is not possible for undergraduates to be involved in actual incident investigations due to safety, confidentiality and logistical reasons. The author faced these challenges while teaching an undergraduate elective WSH module in the Project and Facilities Management (PFM) programme in the Department of Building, National University of Singapore.

An educational digital simulation game (DSG) can allow undergraduates to be immersed in an authentic learning environment (Galarneau, 2005), which will help to improve their competency in incident investigation. DSG-based learning provides a safe, cost-saving, and interactive virtual world where students are free to explore and thus, increase their engagement with the topic. Additionally, the simulation game allows provision for undergraduates to make mistakes – which is a form of interactive authentic learning, helping them to understand the process and how their actions affect the outcome of the investigation.

Therefore, in this paper, we will introduce an educational DSG prototype, SafeSim Investigation, that was built based on the nine principles of authentic learning to provide an authentic experience to undergraduate students learning incident investigation (Herrington & Kervin, 2007). The game requires players to collect evidence to unlock clues and recommend actions based on the evidence collected. This paper presents the prototype SafeSim Investigation as a qualitative case study of how a simulation game is designed to implement the pedagogical concept of authentic learning to improve the WSH education is IHL.

Literature Review

Issues in Construction Safety Education and Training

Most construction education is designed with the assumption that knowledge transfer will occur seamlessly though a lecture-based setting (Jonassen et al., 2006). However, this passive teaching approach limits the interaction between the learners and the educator. Furthermore, the lack of application of WSH knowledge often resulted in graduates entering the industry with inadequate safety skills (Pedro et al., 2016).

Placements or internships and site visits to construction sites can potentially be effective forms of construction safety training and education as it enables students to actively experience real-world problems (Haslam et al., 2005). However, due to its logistical, scheduling and safety issues, attachments and site visits are difficult to arrange. Furthermore, site visits are usually carried out in a controlled manner and guided by a site personnel. This would potentially limit the students' opportunity to explore the site freely and it may create a misconception that construction problems are well-defined and can only be solved in a certain way (Lee et al., 2015).

Authentic Learning and Simulation Games

Authentic learning framework provides a framework to guide the design of learning activities that allow students to conduct realistic tasks, act and make decisions like actual professionals in the field,

and produce feasible solutions for specific problem statements (Jonassen et al., 2006). Herrington and Herrington (2006) Have identified the nine principles of authentic learning where educators could adopt to design their teaching and learning activities as shown in Table 1. Herrington and Kervin (2007) Suggested various ways to operationalise the authentic learning framework through different approaches and one of it is using DSGs.

Simulation games replicate reality and they incorporate common game features such as rules and competition (Sitzmann, 2011). Simulation games that are more entertaining is more likely to improve instructional effectiveness (Sitzmann, 2011). Liu et al. (2011) Adopted a simulation game as an approach to guide students' development in computational problem-solving abilities. They found that students who learned computational problem-solving with the game improved their problem-solving skills more than students who learned from traditional lectures.

Evidence of positive behavioural and cognitive changes arising from the use of simulation games have been extensively documented. Games and simulations contribute to cognitive learning outcomes, acquisition of knowledge and understanding of subject matter (Vlachopoulos & Makri, 2017). It also provide safe and interactive virtual worlds where students are free to explore (Guo et al., 2012). The ability to explore freely without any safety implications would increase students' engagement (Goedert et al., 2011). Furthermore, simulation games reward players for completing tasks with increasing difficulty (Vu, 2017), thus encouraging them to continue to learn.

There are considerable benefits for integrating simulations into investigation to facilitate learning from safety incidents. For example, Macrae (2018) used simulation games to improve incident investigation in the context of patient safety. Simulations can be used to develop key competencies in incident investigations such as identifying evidence, interviewing, systems analysis and development of a recommendation (Macrae, 2018).

Table 1: Principles of authentic learning adapted from Herrington and Herrington (2006)

Principles	Definition
Authentic Context	Providing a physical or virtual environment which replicates the way how the knowledge transmitted is used in real life
Authentic Activities	Tasks and responsibilities with real-world relevance, which is ambiguous, complex and to be completed over an extended period
Access to Expert Performance	Having experts in the domain to demonstrate a skill or concept for students to observe and learn from
Multiple Roles and Perspective	Providing opportunities to examine, explore and evaluate problems from the different point of views
Collaborative Construction of Knowledge	Emphasising on teamwork, joint problem solving and social support
Reflection	Opportunity to think about and have a meaning discussion of choices
Articulation	Avenue for learners to present ideas, argue, speak, and write above their growing understanding
Coaching and Scaffolding	Collaborative learning with more able partners to assist and support, and metacognitive help from teachers instead of didactic help
Authentic Assessment	Providing seamlessly integrated assessment within the task with changes to collaborate and produce a polished product

Research Methodology

This study focuses on the undergraduates majoring in Project and Facilities Management (PFM) in the Department of Building, National University of Singapore. The PFM degree programme offers a wide array of modules related to building and construction, and one of the elective modules offered is PF4202 Safety, Health and Environmental Management (PF4202). The testing of SafeSim Investigation game was held during PF4202 tutorial classes. Students were randomly separated into teams of three members at the start of the class. Prior to each session of the gameplay, the tutor will conduct a 10-minute briefing to familiarise the students with the objectives of the tutorial session. The tutor will explain the learning objectives and the controls of SafeSim Investigation. Teaching assistants were also available throughout the tutorial session to assist the students.

Students are also required to complete an online questionnaire at the end of the tutorial. The questionnaire is designed to collect anonymous information of the students' demographic data such as age, gender, and their experience in simulation games. The questionnaire consists of several questions pertaining to the effectiveness of SafeSim Investigation. The questionnaire also collects feedback on the game design, including issues such as user-friendliness and user experience.

The fundamental hypothesis of this study is that "an incident investigation simulation game designed based on the authentic learning framework will improve the perceived authenticity of the learning experience". The prototype SafeSim Investigation game was developed to test this hypothesis and to identify the advantages and limitations in achieving the objectives of the study. In this paper, the game design will be discussed as a reference case study for other educators and researchers intending to implement authentic learning through a DSG. An overview of the game can be viewed through this YouTube video: https://www.youtube.com/watch?v=rGVnmBzR-zA.

Case Study: SafeSim Investigation gameplay

A prototype three-dimensional multiplayer DSG called SafeSim Investigation was developed to provide an authentic learning platform for PFM students. SafeSim Investigation is structured in two parts. In the first part, students role-play as a team of three incident investigators. In the second part of the game, students are to individually recommend appropriate actions to improve WSH of the site based on their findings. The prototype SafeSim Investigation was designed based on the nine principles of authentic learning while still providing the medium for students to understand the procedure and invoke investigative skills throughout their gameplay.

Two subject-matter experts with more than 30 years of construction experience were consulted to provide an accurate representation of the incident cases on construction site. Documentation and content were based on an actual incident case and was modified based on the feedback provided by the subject-matter experts. The virtual world in SafeSim Investigation mimics the actual construction site with a building under construction and a site office. The prototype SafeSim Investigation has a gameplay of about 60 minutes, where the first 45 minutes is allocated to the first part of the game whereby the players will assume the role of incident investigators and collect the different evidence in the virtual construction site, and the remaining 15 minutes is allocated for each player to recommend appropriate actions based on the data collected.

This following discuss the SafeSim Investigation gameplay.

Briefing and Grouping

Prior to each tutorial session during which SafeSim Investigation was played, the tutor will conduct a briefing to explain the learning objectives and highlight that the game objective in SafeSim Investigation which was to investigate the underlying factors of the incident by collecting the evidence found on the virtual incident scene. Teaching assistants were available throughout the session to assist the students. The teaching assistants were required to have played SafeSim Hazards and studied the game mechanics so as to guide the students. Players were briefed on the game controls and at the same time they can access the game guide, which contains the game controls and shortcut keys, at any point in the game by pressing the F1 key. The tutor and the teaching assistants provided the coaching and scaffolding as recommended in the authentic learning framework.

SafeSim Investigation is designed to support a maximum of three players in each team, and multiple teams can be playing at the same time, but in different virtual worlds. Playing in a group also supports the principle of collaborative construction of knowledge highlighted in the authentic learning framework. Team members can communicate with one another through the in-game chat tool. Students are encouraged to use the chat tool to plan their investigation and distribute tasks among their team members. By having the in-game chat tool, it provides an avenue for the players to present their ideas and thus, allowing the operationalisation of the articulation principle of the authentic learning framework. The learning objective of the game is as follows:

1. Identify and evaluate the reliability and usefulness of different WSH evidence,
2. Analyse evidence and information collected using the Event Causation Technique (ECT) (Goh, 2018),
3. Recommend corrective actions and opportunities for continual improvement based on ECT analysis.

Event Causation Technique (ECT) is a technique developed and taught by the author in his undergraduate module (Goh, 2018). ECT is used throughout the game to provide guidance to the players. SafeSim Investigation also provided cinematic to provide the context for the game. In this case, upon logging in using the pre-allocated IDs, the players will be shown a short animation of the player receiving a phone notification about the task given to them, i.e. their game objective (Figure 1). While waiting for the game to load, the game reinforces the players with the controls of the game as shown in Figure 2.

Figure 1: Cinematic to help players understand the context of the game

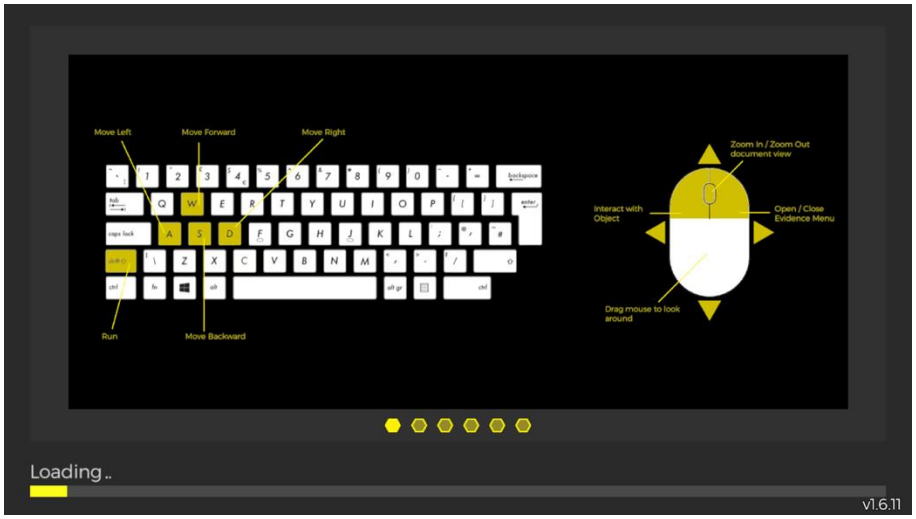

Figure 2: Controls shown on the screen while waiting for the game to load

Collection of Evidence

According to Goh (2018), there are four main types of evidence and they are part, position, people and paper, which is also known as the 4Ps. Evidence under the category of part refers to the material, equipment or parts of the environment, and it is often collected from the incident scene. Evidence in the position category refers to the physical relationship between the part(s) and people involved, and/or the place of the evidence at different point of time. Paper evidence is referred to the documentation involved and often includes close circuit television (CCTV) footage, data log sheets, log books, permits-to-work, and risk assessment. Lastly, evidence that falls under the category of people refers to the interviews gathered from the injured, witnesses and the people associated with the activity.

In SafeSim Investigation, we implemented the 4Ps to categorise the evidence on site. There are three types of evidence that the players can collect in SafeSim Investigation. They are mainly the site evidence, the document evidence and the interview evidence. Players can take up any of these roles (i.e. site investigator, interviewer, document reviewer) at any point of time during the game. Site evidence refers to the items found on the scene or evidence that can be classified as parts according to the 4Ps in incident investigation (Goh, 2018). Document evidence refers to the documentations such as permit to work, medical report, etc. that will help identify the lacking protocols which is classified as paper under the 4Ps (Goh, 2018). Lastly, interview evidence refers to the interaction with the non-playable characters (NPCs) to gather information from the people who were involved when the incident happened (Goh, 2018). Players are expected to find evidence that unlocks the ECT Clue which eventually shows the underlying factor of the accident. It is also noted that evidence collected by other teammates will be recorded into the system to prevent duplication of work.

Apart from correctly identifying the evidence, players are also required to answer the quiz attached to the evidence to obtain a point as illustrated in Figure 3. No points will be deducted for wrongly answered quiz – i.e. they will receive immediate feedback based on their choice. Marks will not be given for the subsequent tries after the answer has been revealed. SafeSim Investigation will also provide a feedback mechanism, whereby it will highlight the correct answer in instances where the player chooses the wrong option.

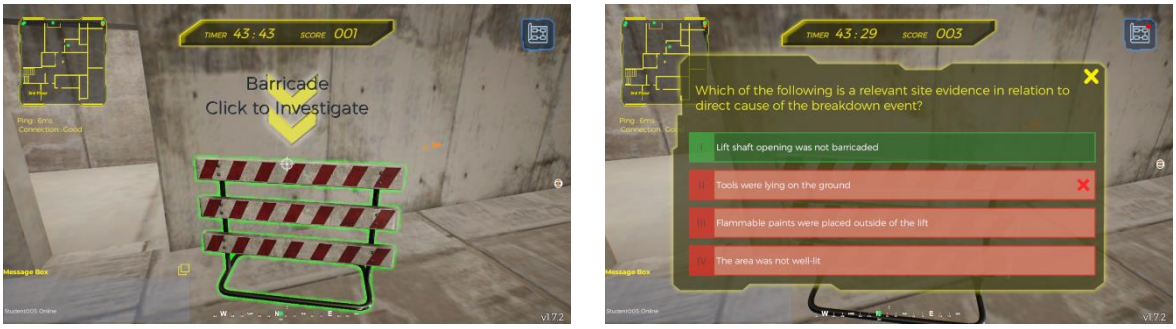

Figure 3: Players will collect site evidence (left) and an interface with a relevant question pertaining to the evidence will pops out to assess the player's rationale (right)

For document evidence, players are required to review the documents and click on the red overlay before it is collected as an evidence. Once the player has collected the document evidence, they are required to click on the 'Quiz' button at the top-right corner to answer the corresponding quiz in order to get the full score and unlock the ECT clue. This is illustrated in Figure 4.

Figure 4: Only items with red overlays are collectable and will count to the scoring system (left) and the quiz window (right)

Interaction with non-playable characters (NPCs)

In order to collect the interview evidence, players can click to interact with the NPCs. A list of questions that can be asked will be available on the right side of the screen as illustrated in Figure 5. To make the conversations authentic, the dialogues of the NPCs were crafted based on conversations found on sites in Singapore and voice actors were used to record the voices of the NPCs. For example, the players will hear the Chinese workers speak in Mandarin and see the translation on the screen.

Figure 5: Players can choose from the list of options on the right to interview the NPCs

Guidance

Proper guidance is crucial in allowing the players to understand the investigative process. Furthermore, majority of the students does not play simulation games and thus, require extra assistance in order to achieve the learning objectives. We provided an Event Causation Technique (ECT) diagram whereby the players can follow through the hints to unlock the ECT clues. ECT guides the investigative process starting with the work context, incident sequence and so on as shown in Figure 6.

The diagram in Figure 6 is easily accessible during the game by clicking on the button at the top-right corner of the game screen. The black cards contain clues to guide players on what, how or who to investigate. For example, for ECT Clue (4) in Figure 6, the player is required to review the Safety Violation List and interview one of the NPCs. Once the player has unlocked the clue, the card will turn green as shown in the ECT Clue (3) in Figure 6. It is also advisable to unlock the cards from left to right as taught by the author in his lectures.

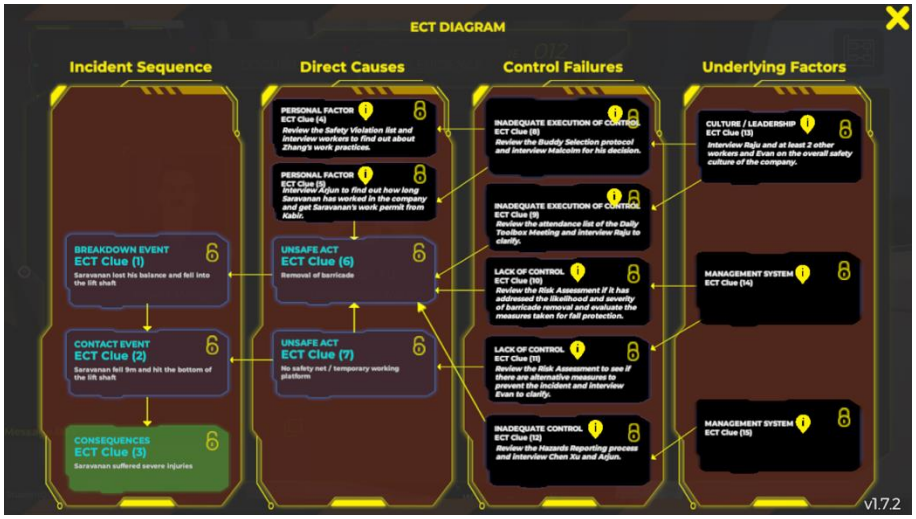

Figure 6: ECT diagram to guide the players

Recommending Actions

Once players have unlocked all the ECT clues, the players will be prompted to enter the second part of the game. A step-by-step guide is offered to the players on how to navigate the user interface. This is illustrated in Figure 7.

Figure 7: Players will be prompted to enter the second part of the game (left) and step-by-step guide provided to guide players of the user interface (right)

We have provided a list of improvement actions on the right, where the players are required to drag and drop to the appropriate ECT clue cards as shown in Figure 8. Players are also required to select the type and importance through the dropdown menu before submitting their answers for scoring.

Figure 8: List of recommended actions (left) and dropdown menu to determine the type and importance (right)

Submission and Review

Once the players have completed both part one and part two of the game, SafeSim Investigation will generate the total score of the player and their teammates as shown in Figure 9. Players can review their collected clues and quiz answers by clicking on the 'Review' button. This allow the players to assess their performance, review the items that has been collected by their teammates, and to see the model answer as shown in Figure 10.

Figure 9: Scoring screen of SafeSim Investigation

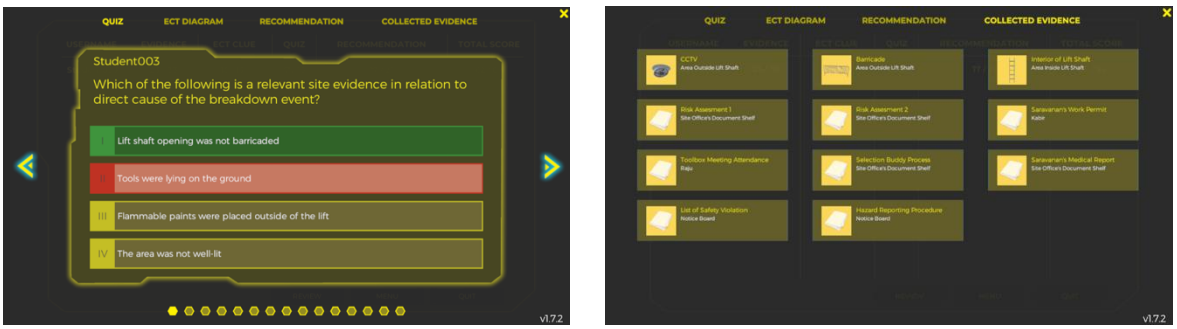

Figure 10: Review of the items collected and see model answers for the quizzes

Analysis

There is a total of 91 participants and all of them are PFM students enrolled in PF4202. Over 67% of the participants have experience in DSG, and over 59% enjoyed playing DSG in general. With a mean rating of 3.13 out of 4, students perceived that the incident investigation simulation game designed based on the authentic learning framework improves the perceived authenticity of the learning experience. Most students find the DSG-based learning realistic and interactive. Students commented that the prototype SafeSim Investigation was engaging and highly effective for their learning. Most of the comments suggested that the authentic dialogues and NPCs voices are highlights of the game.

Conclusions and Further Research

This study presented a prototype digital simulation game, SafeSim Investigation, which was used to teach investigation to undergraduate students and practitioners in adopting educational DSG in WSH education. The prototype SafeSim Investigation game tested by both practitioners and students and they provided positive feedback during the study. The data collected were analysed and based on the feedback given by the students, the prototype game was deemed to be generally effective for learning by the students.

However, there were also several recommendations for improvement. Key considerations are highlighted to improve the gameplay in terms of enhancing the game's intuitiveness and playability for non-gamers. More research and case studies need to be conducted to test the effectiveness of digital simulation games and develop guidelines to improve the effectiveness of WSH education.

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References

Bell, T., Cockburn, A., McKenzie, B., and Vargo, J., 2001. Digital lectures: If you make them, will students use them? Constraints on effective delivery of flexible learning systems. Interactive multimedia electronic journal of computer-enhanced learning, 3(2).

Bureau of Labor Statistics, 2019. Census of Fatal Occupational Injuries. [online] Available at: https://www.bls.gov/charts/census-of-fatal-occupational-injuries/number-and-rate-of-fatal-work-injuries-by-industry.htm

Dipiro, J. T., 2009. Why do we still lecture? American journal of pharmaceutical education, 73(8), pp.137-137. https://doi.org/10.5688/aj7308137

Galarneau, L., 2005. Authentic Learning Experiences Through Play: Games, Simulations and the Construction of Knowledge. Available at: https://doi.org/10.2139/ssrn.810065

Goedert, J., Cho, Y., Subramaniam, M., Guo, H., and Xiao, L., 2011. A framework for Virtual Interactive Construction Education (VICE). Automation in Construction, 20(1), pp.76-87. https://doi.org/https://doi.org/10.1016/j.autcon.2010.07.002

Goh, Y. M., 2018. Introduction to Workplace Safety and Health Management: A Systems Thinking Approach. World Scientific Publishing Company Pte Limited. [online] Available at: https://books.google.com.sg/books?id=mmfMwQEACAAJ

Guo, H., Li, H., Chan, G., and Skitmore, M., 2012. Using game technologies to improve the safety of

construction plant operations. Accident Analysis & Prevention, 48, pp.204-213. https://doi.org/https://doi.org/10.1016/j.aap.2011.06.002

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., and Duff, A. R., 2005. Contributing factors in construction accidents. Applied Ergonomics, 36(4), pp.401-415. https://doi.org/https://doi.org/10.1016/j.apergo.2004.12.002

Herrington, J., and Kervin, L., 2007. Authentic Learning Supported by Technology: Ten suggestions and cases of integration in classrooms. Educational Media International, 44(3), pp.219-236. https://doi.org/10.1080/09523980701491666

Herrington, T., and Herrington, J., eds. 2006. Authentic Learning Environments in Higher Education. IGI Global. https://doi.org/10.4018/978-1-59140-594-8.

Jonassen, D., Strobel, J., and Lee, C. B., 2006. Everyday Problem Solving in Engineering: Lessons for Engineering Educators. Journal of Engineering Education, 95(2), pp.139-151. https://doi.org/10.1002/j.2168-9830.2006.tb00885.x

Lee, S., Nikolic, D., and Messner, J. I., 2015. Framework of the Virtual Construction Simulator 3 for Construction Planning and Management Education. Journal of Computing in Civil Engineering, 29(2), 05014008. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000388

Liu, C.-C., Cheng, Y.-B., and Huang, C.-W., 2011. The effect of simulation games on the learning of computational problem solving. Computers & Education, 57(3), pp.1907-1918. https://doi.org/https://doi.org/10.1016/j.compedu.2011.04.002

Macrae, C., 2018. Imitating Incidents: How Simulation Can Improve Safety Investigation and Learning From Adverse Events. Simul Healthc, 13(4), pp.227-232. https://doi.org/10.1097/sih.0000000000000315

Ministry of Manpower. 2019. Workplace Safety and Health Report (January - June 2019). Ministry of Manpower. [pdf] Available at: https://www.mom.gov.sg/-/media/mom/documents/safety-health/reports-stats/wsh-national-statistics/wsh-national-stats-2019.pdf?la=en&hash=6D52E18A099E8E83EA4F8836981F3463

Pedro, A., Le, Q. T., and Park, C. S.,2016. Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality. Journal of Professional Issues in Engineering Education and Practice, 142(2), 04015011. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000261

Sitzmann, T., 2011. A meta-analytic examination of the instructional effectiveness of computer-based simulation games. Personnel Psychology, 64(2), pp.489-528.

Vlachopoulos, D., and Makri, A., 2017. The effect of games and simulations on higher education: a systematic literature review [journal article]. International Journal of Educational Technology in Higher Education, 14(1), 22. https://doi.org/10.1186/s41239-017-0062-1

Vu, D., 2017. An Analysis of Operant Conditioning and its Relationship with Video Game Addiction.