THE IMPORTANCE OF ENGAGING ENGINEERING AND CONSTRUCTION LEARNERS IN VIRTUAL WORLDS AND SERIOUS GAMES

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ABSTRACT: *The engineering and construction industries require their workforce to undertake complex learning and training activities. Exposing new employees, graduates, or apprentices to these environments could endanger their safety and the safety of those working with them. On site education and training also requires an investment of time from skilled individuals and companies. Problems accessing environments, such as construction sites, heavy plants or chemical manufacturers, are substantially heightened by the need to risk assess and comply with Health and Safety legislation making the traditional "hands on" and "shadowing" approaches to training and education more complicated than in the past. These difficulties are also compounded by changes to the geographical locations (e.g. distance learning, on site) of those studying to join these career paths or progress within them. Therefore, educational institutions and trainers must consider how to deliver this skill based learning for both those with access to academic premises and those learning at a distance. New technologies such as serious games are one of the solutions being explored.*

This paper undertakes an analysis of safety issues and safety training and learning methods relating to the construction industry. The paper takes its start point from a Health and Safety Executive commissioned report in 2003 (Hide et al, 2003) and questions if sufficient improvements in safety have been achieved within the construction industry since its publication. Then, the paper investigates the development of education and training that meets the necessary reality and complexity of engineering and construction sectors and the ability of serious games to provide timely and accessible training to achieve competency within these sectors.

KEYWORDS: *Competency, learning, safety, serious games, training, virtual worlds*

1. INTRODUCTION

The environments in which engineering and construction industry personnel operate require high levels of competency to prevent potentially devastating incidents and accidents, or even to cause widespread harm to the surrounding population (Anderson, 2007). Hide et al (2003), suggested that safety in the construction industry was of increasing concern as accidents within this sector were not only increasing in numbers, but also in severity. More recent data suggests that, although there has been a decrease in fatal injuries, this decline may, in part, be due a decrease in activity associated with the economic downturn (Bureau of Labor Statistics, 2011) and that incidents are still more common, per workforce representation, in construction than in other industries (Health and Safety Executive, 2011). This appears to reflect the international trend (Fang & Wu, 2013).

Most (70%) construction accidents were caused by human factors associated with employees' actions, behavioural traits and competency (Hide et al., 2003). Lack of Personal Protective Equipment (PPE), inadequate PPE, or a failure to use PPE correctly were common factors; PPE can only be effective if it is supplied and used correctly by the workforce (Lombardi et al., 2005). Hide et al. (2003) also identified factors such as travel around the construction site, employee actions and poor team communication as common causes. It has been suggested that the inclusion of an increased number of migrant workers lead to problems with effective communication (Bust et al, 2008) although a study in Canada also suggested that the risk is higher among immigrants whose education exceeds that of job requirements compared with other immigrants (Premji & Smith, 2012).

Hide et al. (2003) also considered other causes, such as failure of the materials and equipment used by employees and poor site design and layout. The design of the construction site was also one of the fundamental areas identified as being responsible for injuries to workers considered by Toole (2002) and by Rajendran & Gambatese

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(2009). The boundaries and access points should provide safe egress for construction employees; however, as members of the general public may come into close contact with the site entrance they are also at risk and must be taken into account (Sawacha et al, 1999).

1.1 Training and learning methods

All of the factors considered above have some human component, either in employer responsibilities or employee actions. Training is often seen as an effective way to improve behaviors and, sometimes, attitudes, although behavior and working patterns of individuals are influenced by many factors, including the central beliefs and attitudes of each individual and the social norms experienced by individuals (Lapinsky et al, 2005; Parker, 2006; Young, 2007). Training endeavors to impart knowledge, skills and attitudes necessary to perform job-related tasks (Truelove, 1992: 273). Learning is generally defined more holistically as a process that encompasses both training and education (Jensen, 2001) with training seen as 'learning by doing' and education as 'learning by thinking' (Garavan, 1997: 42). Training is defined as learning that is provided in order to improve performance on the present job (Nadler, 1984). Active training is defined as instructional activities involving learners in doing things and thinking about what they are doing (Bonwell & Eison, 1991) and as a form of learning in which the learner uses opportunities to decide about aspects of the learning process or as the extent to which the learner is challenged to use his or her mental abilities while learning (VeldhuisDiermanse, 2002). Proponents of active learning share an underlying assumption that the learner is self-reflective and actively engaged as a participant in his or her interactions with the world (Sarason and Banbury, 2004). Passive training is form of training in which learners do not receive a feedback (Rae, 1995). Examples of passive training methods are videos, lectures or any classroom-style training methods without feedback. An overview of the different training methods is reported in figure 1. The ability of such techniques to meet the reality and complexity of engineering and construction contexts is discussed in the following sections using an extensive literature review.

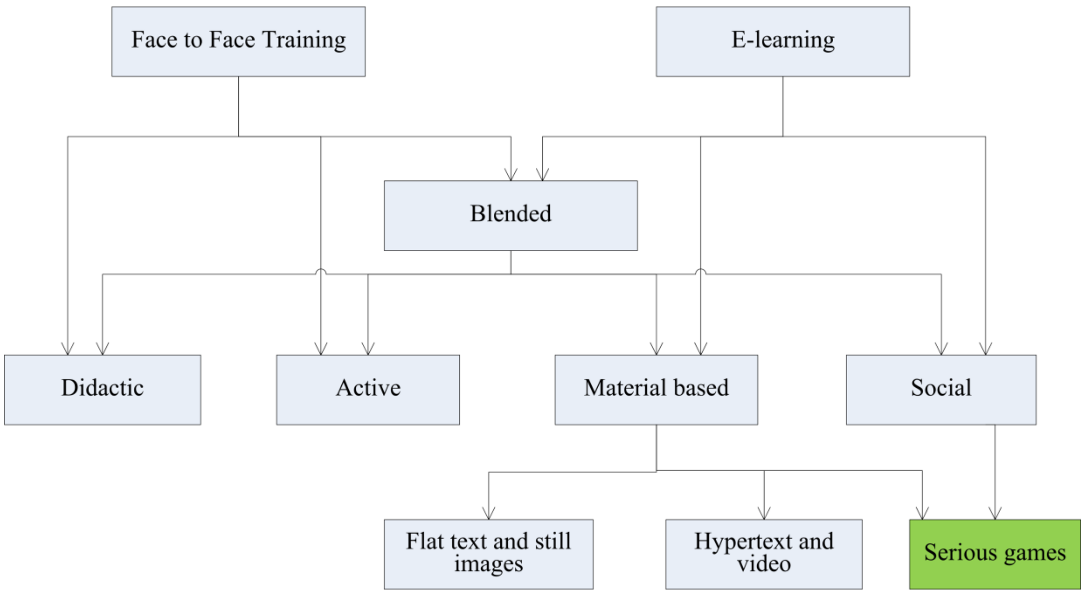

Fig. 1: Categorisation of Training in the Construction Industry

1.2 Challenges affecting the provision of training

There are many regulatory and commercial drivers in the EU that lead most companies to offer health and safety training to their employees (Felstead et al, 1999; Felstead et al, 2012). In the UK, the provision of training is supported by the ConstructionSkills levy scheme; an annual levy from employers is used to fund employers for training their workforce through programmes such as Construction Plant Competency Scheme (CPCS) and Site Safety Plus (Gambin et al, 2012). Despite this, the Health and Public Services Committee (2005) reported complacency about worker injury with less than a third of construction firms have training plans or a training budget. There were also concerns that, while the incidence of training may steady or even be increasing in the UK, the intensity and effectiveness of training may be falling, with training effort being spread more thinly among a higher proportion of workers (Felstead et al, 1999). Similarly, in the US, Van Buren & Erskine (2002) reported that, although the construction sectors has a high uptake of training (over 90% of employees receiving training), it was also one of the sectors with the lowest number of hours spent on training (15.3 hours per eligible employee) and with the highest ratio of employees to trainers (685:1). Goldenhar et al (2001) found that only 62% of employees questioned felt they had received Health and Safety training.

The fast pace of many building projects and tight deadlines can often impede effective safety training (Wall and Ahmed, 2008). One of the risk factors is the itinerant and casualised nature of employment in this sector (Health and Public Services Committee, 2005). The greater vulnerability of precarious workers has led to the development of the Pressures, Disorganization and Regulatory Failure (PDR) model, within which poor quality or absent training is seen as a serious risk factor (Underhill & Quinlan, 2011). Increased pressure on the training budget has also led to a tighter focus on specific business needs and increasing use of members of the regular workforce or a trade union representative to deliver training (Health and Public Services Committee, 2005; Felstead et al, 2011) and an increased interest in e-learning (Felstead et al, 2012).

1.3 The Quality of Training Provision

If training is to be fully effective it needs to have an impact on attitudes as well as behaviours. Somerville and Lloyd (2006) distinguished between how workers are trained to work safely and how they learn to work safely in workplaces, including building construction, and drew attention to the failure of safety training that was mediated through what they referred to as ‘codified knowledge practices’ associated with competency-based training. They considered that, in such training, the social and physical environments of the workplace are ignored and called for increased emphasis on these aspects of learning. The use of passive learning, often video scenarios and classroom type delivery at short ‘toolbox talks’ may be ineffective (Loosemore & Andonakis, 2007) and there has been concern that rapid initial training based on a didactic style may lead to confusion and misunderstanding (Guo et al, 2012). Cherrett et al (2009) identified the failure to capture the attention of learners sufficiently to impact on their ability to retain information and identification triggers for hazards. There may be additional difficulties if there are language barriers (Loosemore & Andonakis, 2007) and, as time is limited with many building projects, training is likely to be squeezed into the minimal amount of time possible (Felstead et al, 1999).

Hands-on and practical learning strategies allow a more active approach and are examples of Situated Learning, giving learners a chance to engage and make connections between the theoretical and the application. Participatory, peer led training was found to have a positive effect on attitudes, practices, and self-reported injury rates (Williams et al, 2010) but this usually takes place most effectively over an extended period of time, such as via an apprenticeship (Lave & Wenger, 2009).

The effectiveness of training can be linked to the quality of the provision, but it has long been known that the climate within a company, and the trainee’s relationship with the company, can also have a positive or negative impact on training outcomes (Richey, 1990). Experience from related industries, such as mining, suggest that the interaction between how engaging the training experience is and the perceived hazardous nature of the industry can also have a significant impact on training outcomes (Burke et al, 2011) and, following a limited study, Edwards & Holt (2008) reported that perceived characteristics of training regimes used by employers did not appear to impact the outcomes of written tests of employees’ health and safety knowledge.

2. E-LEARNING AS AN OPTION FOR SAFETY TRAINING

2.1 Information Transfer and e-Learning 1.0

Traditional uses of information technology (IT) and virtual learning environments (VLE’s) have been materials based, as repositories for content (Nash, 2005; Minguillon et al, 2011). This provides easy and immediate access to content, but does not necessarily offer the benefit of contextualised and collaborative learning opportunities for participants (Acar et al, 2008; Addison & O'Hare, 2008). Materials are often accessed in support of a passive learning experience and content may include digitised versions of paper based information, video and pictorial content, lacking opportunities for dynamic interaction (Clark & Maher, 2001). Cherret et al (2009) suggest the shortcomings of basic streamed video can be significantly improved by endeavouring to make videos interactive through links to simulations and graphics amongst other learning materials. Arslan & Kivrak (2013) report the use of dramas and animations in Turkey to present construction accidents, claiming that visual materials can minimize accidents more effectively than purely theoretical training, especially for workers entering construction with a low level of education. Wall (2007) proposed the development of a virtual classroom framework with the specific focus on health and safety training for the construction industry. Using Gardner’s (1983) work on multiple intelligences, which was originally intended to be applied to classroom based delivery, it was suggested that interactive material from webinars, hot spots in videos with images and photographs could be used to develop a learning activity.

The use of video, drama and hotspots allows learners to interact with the materials but they do not necessarily interact with their fellow learners or the trainer and, even with high quality materials, the e-learning 1.0 model is essentially isolating and individual. This makes it unattractive to students and possibly ineffective. It is unlikely that this approach can be seen an improvement on the toolbox talk, where there is at least the potential for communication with the trainer, although learning may be enhanced with a blended delivery approach, combining some face to face activity with support materials loaded to the VLE (Mackey, 2008).

2.2 Social E-Learning and e-Learning 2.0

Interaction and social collaboration in learning has often been identified as positive (Vygotsky, 1978; Deforges, 1995; Lombardi & McCahill, 2004; Wenger, 2008). E-learning 2.0 recognizes the importance of shared learning within a social context, rather than delivering static, passively learnt information (Dagada & Jakovljevic, 2004; Acar et al, 2008; Rajendran & Gambatese, 2009). While distance learning has been successfully transposed using IT where webinars and discussion groups have been a part of the learning design (Blanchard et al, 2006), Lombardi & McCahill (2004) are concerned that the current mechanisms available within VLE's do not provide the support offered by successful learner-centred communities based on constructivist pedagogy, suggesting that the sense of being within a learning space with other learners is lacking. Dagada & Jakovljevic (2004) identified the lack of social presence as a potential drawback for some learners who prefer to have the physical presence of tutors and other learners. Acar et al (2008) acknowledge the limitations of the experience for participants, recording participant satisfaction with the synchronous and asynchronous use of whiteboards and screen sharing as less favorable than face to face learning. Wang et al (2012) undertook a review of e-learning 2.0 studies and concluded that, while there is limited research comparing learning in conventional and e-Learning 2.0 environments, e-Learning 2.0 does appear to enable social learning and effective learning, with the potential to transfer learning to untrained tasks. However, there remains the question of how effective this approach will be for safety training on construction sites. Although it reintroduces the potential for social interaction, it is not necessarily practical in the way that "hands on" or "on site" learning might be. However, examining an array of safety learning and training methods (i.e. hands-on, lectures, films, video-based training, behavioral modeling and simulation) in terms of safety knowledge imparted, safety performance improved and safety outcomes, Burke et al. (2006) concluded that as the methods became more engaging and requiring trainees' active participation, workers demonstrated greater knowledge acquisition and reductions were seen in safety accidents and injuries.

3. VIRTUAL REALITY AND SERIOUS GAMES

The introduction of Virtual Worlds and Virtual Reality (VR) may hold the key to implementing a social element to e-learning strategies in the construction training. Serious Games and Games Based Learning (GBL) have become an area of interest to both educators and trainers over the last decade (Corti K, 2006). VR and GBL have the potential to provide not only the information required by learners, but the opportunity to build on that information together and so construct knowledge through that collaborative experience (van Nederveen, 2007).

Advances in technology and the use of simulators have learners to engage in simulated realities with rich visual and audio production and 3D environments, possibly displayed on wrap round screens, eliciting a semi-immersive response to the scenario (Westera et al, 2008; Ku & Mahabaleshwarkar, 2011; Goulding, 2012). In other fields, the immersiveness of this experience is sometimes further enhanced using a haptic interface to provide further sensory triggers for the participant, for example in rehabilitation (Rego, Moreira, & Reis, 2010) surgery (Våpenstad et al., 2013) or in flight simulators. The use of GBL may allow a type of Situated Learning, providing a similar opportunity for learners to engage and make connections between theory and application (Squire, 2006) and evidence is growing that the immersive and repeatable aspects of serious games allow participants to learn through doing in an Experiential Learning style (Coyne, 2003; Van Eck, 2006; Susi et al, 2008; Goulding, 2012). Westera et al (2008) suggest that GBL can be used to provide participants with the necessary detail to allow them to learn complex skills through focused scenario-based games. Lin et al (2011) suggest that static pictures of hazards limit learners discussions to what is in the image, whereas walking a 3D simulation provides them with the opportunity to link different factors identified in the walk through, potentially promoting deep learning rather than surface learning. Combining Web 2.0 technologies with VR has proved popular with students (Wang et al, 2012). Simulations have been found to help contextualise learning for participants in the construction industry (Wall & Ahmed, 2008).

There are simulations and virtual worlds available that run on simple desktop computers and open source options provide an inexpensive option to experiment with the development of serious games to suit industry requirements. For example, the use of virtual worlds such as Second Life may provide options for low cost developments that emulate real world activities (Boulos et al, 2007). Virtual environments such as this have the advantage of allowing creators to access other user created content, thus speeding up the build phase of activity development (Kaplan & Haenlein, 2010). Two examples of rapidly construction site scenarios developed relatively rapidly in Second Life are shown in Figure 2. In addition the collaborative opportunities for learners within the virtual environment may offer a distinct advantage over the rigid and individual human to computer interface often experienced with serious games designs (Antonacci & Modress, 2008). Ku & Mahabaleshwarkar (2011) used Second Life to deliver construction safety to students. Students were asked to collaborate to create content (buildings) whilst considering safe working practices. The limitations of this approach were mostly related to the challenges making the environment 'real' due to relatively unsophisticated graphics and limited representations real world physics, but the authors found that the learning experience was still effective.

Lin et al. (2011) have considered how closely the game or environment has to emulate reality in order to create the desired immersive sensations and reactions, suggesting that high realism may not be cost effective in terms of developing effective educational games for some applications. To emulate reality and in particular the evolving construction site over time, Miller et al. (2012) have proposed to embed the concept of 4D planning (i.e. 3D virtual content changing over time) within the virtual world. Lin et al. (2011) suggested that reality can be emulated in a cost effective way by using traditional images and video footage within the game, but recognised that this may break the sense of presence and interrupt the learning activity. This limitation might be addressed through the use of an integrated Head-up Display (HUD) system within the virtual world platform of Second Life. For example, the developer of the Prohawk HUD has designed it to deliver an uninterrupted learning experience using scripted objects that provide feedback and guidance to learners. This allows participants to make choices, for example about the correct tools for excavation of particular layers of earth, and to learn from their choices (Romulus, 2011). Information about performance of participants throughout the task can also be gathered by the HUD system and reported back to trainers.

Fig. 2: Site safety explored in a virtual build

3.1 Virtual Prototyping

As well as generic safety skills and knowledge, construction workers, the safe design of sites is also important (Hide at al., 2003). Virtual Prototyping and 4D solutions are already employed in the design of safe sites and in the education of civil engineers and architects. Virtual Prototyping (VP) uses modeling and simulation to aid in the identification of unsafe factors in site design and can also be used to provide safety training. Goedert et al (2011) suggest that the use of simulations in the education of students intending to enter the construction industry can produce graduates who are competent for that entry to the workplace. The use of 3D and 4D (3D +time) modeling to aid architectural and engineering student development was found to be extremely valuable (Lee et al, 2011). The ability for students to be able take a 2 dimensional design and reconstruct it within a virtual environment that supports 3D or 4D modeling allows the student designers to investigate their build design from the perspective of an end user. Guo et al (2013) have presented a case study demonstrating the use of VP to improve the safety performance of construction projects.

Shen at al (2012) used building information modelling (BIM) to develop a 3D learning activity aimed at educating hospital facility management, concluding that virtual environments offered the opportunity to provide learning and training where the context of a particular built environment was important to the learning. Workers need to be able to recognise specific hazards associated with particular construction sites, especially complex sites and there have been calls for better methods to develop hazard recognition skills among new workers (Albert & Hallowell, 2012). Applying this approach within a construction scenario may provide participants may address some of the issues previously discussed by Dagada & Jakovljevic (2004) and Acar et al (2008).

4. CONCLUSION

Traditional face to face delivery of health and safety training in the construction industry, for example via toolbox talks, does not seem to be changing attitudes and so is not making a significant impact on the numbers of accidents (Choudhry & Fang, 2008). As further pressure is placed on training budgets, through time constraints and the increased training needs of a vulnerable workforce, there may be a significant deterrent to providing high quality training, including hands on practical training. The introduction of e-learning 1.0 may be a step backwards if a flat materials based approach is adopted, and while the advantages of social learning styles are acknowledged, it is considered unlikely that discussion forums and some other approaches used in the e-Learning 2.0 will be effective at this level. On the other hand, the introduction of a GBL model using simple VR to address the needs of both learners and employers may provide a flexible, adaptable and cost effective solution. The increased use of the VP outputs in safety training for site staff may also be beneficial in providing context specific training.

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