POTENTIAL FOR VIRTUAL REALITY AND HAPTIC FEEDBACK TO ENHANCE LEARNING OUTCOMES AMONG CONSTRUCTION WORKERS

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ABSTRACT: *The construction industry involves highly hazardous working conditions, where workers need to identify and assess a litany of risks on jobsites resulting from the varied high-energy work being performed around them. Research suggests that, while the traditional training approaches offer value, they do not sufficiently prepare workers to eliminate preventable injuries. Emerging technologies offer opportunities to leverage immersive virtual environments to train construction personnel about safe practices. This research reviews the uneven literature across various domains and examines how virtual technologies and haptic feedback has been used for targeted training experiences. The results of this work illustrate that there are many different learning advantages reported for VR and haptic environments for various fields. There is also evidence to suggest synergies between the two technologies justify the exploration of both in conjunction with one another for adult learning applications. The authors use the findings reported in these prior studies to theorize potential learning benefits that the construction industry could gain by adopting immersive simulation-based training environments. The effort here also identifies how immersive training environments can generate targeted emotional arousal and increase situational interest to meet safety-related learning objectives while also promoting risk-averse decisions.*

KEYWORDS: *Virtual Reality, haptic technology, training, and construction safety.*

1. INTRODUCTION

The U.S. construction industry makes up 6% of the U.S. GDP and accounts for $1 trillion in annual spending (Huesman et al., 2015) and 9 million American jobs (Dong et al., 2014). However, the industry has struggled with productivity and wastes of about $15.8 billion annually due to inoperability (Gallaher et al., 2004) and another $15 billion in direct costs stemming from occupational fatalities and injuries.

Recent studies have highlighted that the current format of skill and safety training sessions are not engaging and often present information in a manner that cannot be easily retained by adult learners (Albert and Hallowell 2013). From a safety training context, Albert et al. (2014) showed that workers are engaging in unsafe behavior perhaps unwittingly because the conventional safety training programs are ineffective at improving their hazard recognition skills. This incompetency is the result of the framework of these safety training programs that uses child-focused pedagogical principles (Albert and Hallowell, 2013) which makes them not only ineffective in promoting learning, also leads to instilling a negative outlook towards learning among workers (Haslam et al. 2005). *This 'teacher-student' passive learning framework for training is not conducive to positive learning environment for construction workers.* Furthermore, it would be fair to hypothesize that there is going to be a massive influx of semi-skilled workers to address the critical labor shortages facing the industry right now (Wang et al., 2010). Thus, the industry could benefit significantly by revolutionizing the design and delivery of the various training programs to encourage workers to engage within the learning environment and also enhance their long-term knowledge retention.

Researchers have started to explore the efficacy of using virtual reality (VR) technology within construction safety training contexts to create immersive environments to test hazard recognition (Tang et al., 2009), risk assessment (Tixier et al., 2014), and decision-making (Bhandari et al., 2018) skills. The use of high-fidelity VR environments allows researchers to expose individuals to risks without causing actual harm. Similarly, haptic feedback has been used within the construction context to provide error feedback and defect management for workers (Dong et al., 2009; Kosch et al., 2016). While VR environments have been successfully used to measure skill and decision-making abilities, studies have not explored if these immersive environments and feedbacks can enhance learning outcomes among workers. Specifically, it is unclear if providing experiential learning on construction projects can translate to enhanced skills and safer practices on the construction site. The purpose of this paper is to review literature from other domains and propose how use of VR and haptic technology can potentially further learning outcomes among construction workers and identify critical gaps in body of knowledge for future research endeavors.

2. OVERVIEW / BACKGROUND

In the section below, we examine the relevant literature related to using VR and haptic feedback for training and education purposes across diverse domains and how the use of these technologies can instigate and sustain primary psychological precursors to learning. The established theory presented here will be used to ground our discussion on the potential benefits the construction industry can receive by adopting these immersive technologies.

2.1 Psychological Antecedents to Learning

Emotional arousal and interest are strong and immediate precursors to intense learning experiences. Both are key learning agents as they generate and mediate a learner's cognitive functioning (Renninger, 2000), motivation (Pekrun et al., 2011), attention (Hidi et al., 2004), commitment to learning (Schiefele, 1999) and knowledge retention (Brown and Kulik, 1977).

Emotional arousal is a fundamental component to experiential learning. Experiencing an emotional response in a learning environment can motivate learners to pursue or continue to engage with the information being provided by heightening curiosity or instill a need to improve performance (Konradt et al., 2003). Studies have found that students who experience emotional arousal in a learning environment are more likely to recall and remember the information (Chung et al., 2015). Furthermore, Brown and Kulik's (1977) flash-bulb theory suggests that events with strong emotional impact can remain well-preserved in our long-term memory. This implies that training sessions that provide information with relevant and impactful emotional cues would be less likely to be corroded easily from memory, thereby improving long-term retention of knowledge.

Both positive and negative emotions can enhance learning experiences. Positive emotions promote intrinsic motivation and creative thinking (Bless et al., 1996) whereas, negative emotions can generate extrinsic motivation and promote a more cautious and detail-oriented approach to problem solving (Pekrun et al., 2002). Appropriate emotional responses within learning environment can aid learners to adequately assess, categorize, and value the information being presented. These findings underscore the importance of experiential learning (Chung et al., 2015) since sensory experiences and active learning techniques yield greater emotional arousal than passive lectures and presentations (Bell and Kozlowski, 2008; Um et al., 2012). Moreover, emotional arousal during training environments can also be used to influence risk-taking behavior and safety decisions (Tixier et al. 2014).

Additionally, interest experienced by a learner in a subject has been noted by researchers as a critical driver of long-term engagement with learning as well (Hidi and Renninger, 2006). There are two primary forms of interest: *individual* and *situational* where individual interest has been characterized as a deep and enduring personal connection with subject matter whereas situational interest is immediate and fleeting experience where interest is associated with stimulus within the environment in that moment (Hidi and Renninger, 2006). Situational interest is a strong predictor of willingness to apply cognitive resources to acquire and apply knowledge (Ainley et al., 2002). This paper focuses on situational interest because it is more relevant to consider immediate and short-term reactions to training environments however, Hidi and Renninger (2006)'s interest model suggests that a pervasive learning environment that sustains situational interest can develop into meaningful and well-developed individual interest. Because current safety training frameworks can often be mundane and do not incorporate adult learning principles (Albert and Hallowell, 2013), a focus on generating situational interest can yield not just a more cognitively motivated workforce, but also one that is emotionally and behaviorally engaged (Sun and Rueda, 2012).

Therefore, in summary training programs need to provide active learning environments with agents to generate both situational interest and targeted emotional arousal to improve engagement, enhance knowledge retention, influence behavior, and address the negative outlook towards training in the workforce.

2.2 Use of VR for Learning and Training Purposes

VR simulation can be characterized as computer-generated synthetic immersive environment that allows a person to interact with reality (Briggs, 1996). These immersive environments are often used by researchers to study an individual's perceptions and behavioral tendencies by simulating reality without incurring significant costs and within certain experimental contexts, circumventing the need to place someone in real danger. VR environments have received significant attention from the research community and its efficacy within learning (Merchant et al., 2014; Youngblut, 1998) and training (Lateef, 2010) contexts across various domains has been rigorously validated.

Immersive VR environments can be effective in enhancing attention (Cho et al., 2002) and reducing cognitive demand for improved learning experiences (Wetzel et al., 1994). Seymor et al. (2002) conducted a double-blind study on surgical residents and found that the participants with VR training took less time and made fewer errors compared to non-trained participants. Similarly, a plethora of studies have replicated these findings confirming the utility of VR training in improving performance in operating rooms (Grantcharov et al., 2004). Use of VR training can provide learners the opportunity to constantly and consistently train without utilizing significant resources each time (Gallagher and Cates, 2004) and trainers or supervisors can monitor an individual's learning curve (Gallagher and Satava, 2002). Similarly, construction workers also deal with significant time pressure and work in an environment that is dynamic and the risks are ever-changing, thus placing them in VR simulation can serve as a high-fidelity experiential learning tool that can heighten their situational awareness by engaging their visual and auditory sensory experience.

As VR technology continues to increase in fidelity, users will continue report increased *presence* in the environment. The degree of immersion, interactivity, novelty, and challenge by using this technology can yield proportional motivation and mindful engagement (Malone and Lepper, 1987) and self-directed learning (Pantelidis, 1993; Standen and Low, 1996). The level of immersion in a VR environment also generates emotional arousal (Riva et al., 2007), while Edwards and Gangadharbatla (2001) proposed that 3D modalities should increase situational interest. Thus, VR can be an effective tool for training construction workers on technical skills and level of immersion can generate targeted emotional arousal that can enhance learning outcomes and risk-averse decision-making.

2.3 Use of Haptic Technology for Learning and Training Purposes

Just like visual and auditory cues, our sense of touch can influence attitudes, behavior, and judgments (Ernst and Banks, 2002; Peck and Childers, 2003). Haptic feedback is essentially sensory feedback that is generated from kinesthetic and tactile receptors (Botden et al., 2008). The feedback can guide individuals on the speed and direction of necessary movement thereby improving tactile skill (Pantelidis, 1993). Haptic feedback technologies allow a user to interact mechanically with remote environments without being exposed to the risks (Hatzfeld and Thorsten, 2014). This form of feedback has been found to be highly beneficial and is widely used in the medical field to aid in improving skill among residents and patients to improve performance of surgery (Mayer et al., 2007; Okamura, 2004) and improve motor-skills (Jiang et al., 2009) respectively.

Even in other domains, haptic feedback has been used to enhance the transfer of technical skills. Marchal-Crespo et al. (2010) found that haptic training improved car steering performance among all age groups. Primary reason that feedback from haptic devices improves performance could be attributed to gaining physical representation through "feel" of knowledge that learners cannot access in a traditional learning environment (Reiner, 1999). Reiner (1999) also suggests that the gain of such knowledge promotes construction of accurate mental models that learners can easily access. Even under high cognitive load, haptics can improve the speed and accuracy in task performance (Cao et al., 2007).

Like VR being proven to instigate emotional responses, there is evidence that haptic feedback could intrinsically impact emotional arousal (Olausson et al., 2002). A study by Jones et al. (2003) showed that students who received haptic feedback had an overall positive emotional experience in the learning environment and reported more meaningful engagement and interest with the subject matter. These studies suggest that haptic feedback can mediate emotional arousal and the experience of interest among learners that could be used by teachers, facilitators, and managers to enhance learning outcomes.

2.4 Use of Haptic Technology in conjunction with VR

While VR technologies and haptic feedback have been utilized across various domains, their use has been mostly mutually exclusive of each other. But sparse and preliminary evidence suggests that providing haptic feedback within VR environment can be used *further* heighten user presence and sense of realism (Weiss et al. 2009).

Use of haptic feedback with VR technology has aided both sighted and blind people with development of cognitive models and spatial knowledge (Colwell et al., 1998; Jansson et al., 1998). A study by Jacobs et al. (2007) found that, compared to the traditional use of only visual feedback, a combination of haptic and visual feedback can improve an individual's productivity by significantly reducing their task completion times while also reducing the number of errors they commit.

Combining the two technologies has also been shown to improve the transference of the virtual experience to real-world skills (Council et al., 1995) as it improves users ability to make personal connections with subject matter (Jones et al., 2006). Use of haptic feedback within VR environment has been shown to improve the range of motion and speed of hand movement among patients who have suffered a stroke even at chronic stages (Merians et al., 2002). Within learning contexts, the combination of visual and auditory cues from the VR environment and sense of touch from haptic feedback allows learners to utilize multiple channels to process information, build more accurate mental models, and improve retention of knowledge (Baddeley, 1992). Furthermore, the cutaneous sensations alongside visual and auditory information improves memory capacity (Killi 2005; Sweller, 1988; Wickens, 2002) while the novelty of the experience improves curiosity and interest (Richard et al. 1996).

So far within the construction domain, VR technology and haptic devices for feedback have been used independently and sparingly. However, VR environments have only been used as tools to measure skill and behavior but rarely to provide training. Haptic feedback on the other hand, has received nearly no attention from researchers and industry stakeholders within the construction domain. The research that has been conducted is mostly qualitative and speculative in nature (Wang et al., 2007). There is a need to conduct empirically driven exploration to examine if providing high fidelity information from immersive environments improves or hinders acquisition of skill and knowledge among workers.

3. DISCUSSION

The literature review above shows that VR environments and haptic feedback are being commonly used in the various domains to transfer technical skills, enhance learning, and study users' perceptions and behavior when interacting with real-world simulations. Within the construction industry, most training programs use either passive settings (Albert and Hallowell, 2013) or a multimedia learning environment, which includes physical simulations and narration (e.g., Bhandari and Hallowell, 2017) that can be interactive but not immersive in nature. The following section uses the findings presented above to interpolate the theoretical benefits the construction industry can derive by adopting VR+ haptic feedback training format. Furthermore, the authors also identify potential avenues for future researchers to further the current body of knowledge.

3.1 Implications

Research shows that witnessing or sustaining an injury creates a deeper experience and consequently leaves the experiencer with a long-lasting lesson learned (Hallowell, 2010). It is fair to hypothesize that placing workers in a VR simulation and allowing them to make mistakes and deal with the consequences can lower their overall risk tolerance and heighten their situational awareness on actual worksite. This is the reason training programs especially within construction domain need to focus on fostering experiential learning environments (Bhandari and Hallowell, 2017).

Adult learners interact with learning environments differently and their needs are very different compared to children. Passive learning environments generally ignore relevant life-experiences and their cultural backgrounds (Hollins and King, 1994; Merriam, 2004). VR technology and haptic feedback can promote self-directed learning among adults by giving them autonomy to interact with simulated reality. Adult learners are context-driven and truly engage with learning environments if they see information relevant to their everyday life (Lindeman, 1956). Furthermore, real-time feedback can allow the workers to enrich pre-existing knowledge, while gaining new knowledge. Passive learning environments are framed to not allow self-directed learning which adults prefer (Specht and Sandlin, 1991) and coercion experienced in those learning environments (Boyatzis, 2002) could explain the negative outlook towards safety training among construction workers.

To make training a fun and interesting experience, it needs to be unique and interactive. A VR training environment may be perceived as both novel and immersive, which are key factors to triggering situational interest among learners (Hidi 1990). Factors such as engaging narrative, humor, and belongingness (Bergin, 1999) can be easily incorporated in a virtual training environment to sustain that interest of workers. For the construction industry, this coupled with the findings from previous studies showing the use of VR technology and haptic feedback can make individuals more productive, which can address crippling costs incurred due to interoperability and injuries mentioned above. Finally, as mentioned before, emotional arousal can influence not only our learning outcomes, but also our behavior and decision-making abilities. It can be used to control risk-taking behavior and heighten perception of risk (Loewenstein et al. 2001). Specifically, negative emotions can reduce risk-taking behavior by lowering false optimism (Taylor and Brown, 1988) and reduce appraisal of safety (Izard, 1977). Within the construction context, Tixier et al. (2014) showed in a controlled experiment that participants induced with negative emotions showed higher risk-perception when assessing construction hazards compared to participants induced with positive emotions and control group. Similarly, Bhandari and Hallowell (2017) showed that multimedia simulation-based training environments can be used to generate targeted emotional arousal among construction workers. As noted before although typically, positive learning environments are favored, negative emotions can generate extrinsic motivation to avoid failure (Pekrun, 2002) and make learners more detail-oriented and cautious (Bless et al., 1996) which in safety context is more desirable. Table 1 shows that training environments that use both VR and haptic feedback can theoretically enable more learning agents over the more traditional learning environments.

Table 1: Crosswalk table comparing VR and Haptic training combination against other training formats

	Emotional Arousal	Self-directed Learning	Immersive Interaction	Physical Interaction	Experiential Learning	Novelty
VR + Haptic Feedback	X Reiner 1999, Taylor & Brown 1998	X Okamura 2004, Schiefele 1999	X Cho et al. 2002	X Gallager and Sataya 2002	X Gallager and Kates, Gallager and Sataya 2002	X Bergin 1999, Hidi 1990, Malone and Leper 1987
VR	X Reiner 1999, Schiefele 1999	X Okamura 2004, Schiefele 1999	X Cho et al. 2002		X Gallager and Kates, Gallager and Sataya 2002	X Bergin 1999, Hidi 1990, Malone and Leper 1987
Haptic Feedback	X Merriam 2004	X Chien et al. 2010		X Gallager and Sataya 2002	X Kosch et al. 2016	X Bergin 1999, Hidi 1990, Malone and Leper 1987
Multimedia Learning Environment	X Bhandari et al. 2017	X Bhandari et al. 2017		X Bhandari et al. 2017	X Bhandari et al. 2017	
Passive Learning Environment	X Perry & Dickens 1984					

In sum, VR + haptic feedback-based training may be able to be used as tools to induce targeted emotional arousal to manipulate risk perception and promote risk-averse decision-making among construction workers. Furthermore, the incorporation of self-directed learning framework with active learning environment may generate meaningful interest among workers to persevere with learning and dedicate cognitive resources. Finally, realistic and immersive simulations of hazards, risks, and injuries can act as experiential learning components for workers that should lower their risk tolerance and heighten situational awareness. Figure 1 shows the pathways that can lead to these potential improvements in learning outcomes, productivity, and risk-taking behavior.

3.2 Gaps in Knowledge and Future Directions

It has been established that the current methods of safety training are woefully inadequate (Albert et al., 2014) and the use of VR technologies and haptic feedback has been largely successful in other domains. This paper posits that the use of VR technologies with haptic feedback could overcome the shortcomings of the current child-focused pedagogical principles-based training modules currently used on construction sites. However, the implications discussed above have not been empirically tested and need validation.

The qualitative assertions of potential gains that the industry could gain are derived primarily from studies conducted in the medical domain focused on resident surgical training. These findings need to be validated in a construction setting as construction jobsites are much more dynamic in nature (Rozenfeld et al., 2010) and the nature of hazards and risk can vary on each jobsite. There is a need to study if the higher fidelity training systems can improve situational awareness and work performance among the adult learners over the traditional methods of training. Specifically, while we theorize that VR environments and haptic feedback may reduce errors and improve hazard recognition skills, the degree of the improvement that can be expected remains completely nebulous. Finally, it is unclear if the realistic simulations of accidents and injuries resulting from their poor decisions (i.e., experiential learning) would indeed be effective in reducing risk-tolerance levels and attitude towards safety among workers. Addressing these gaps by conducting empirically driven experiments in a controlled laboratory setting would provide more context to the understanding of whether the cost of adopting VR + haptic feedback training is justified or not.

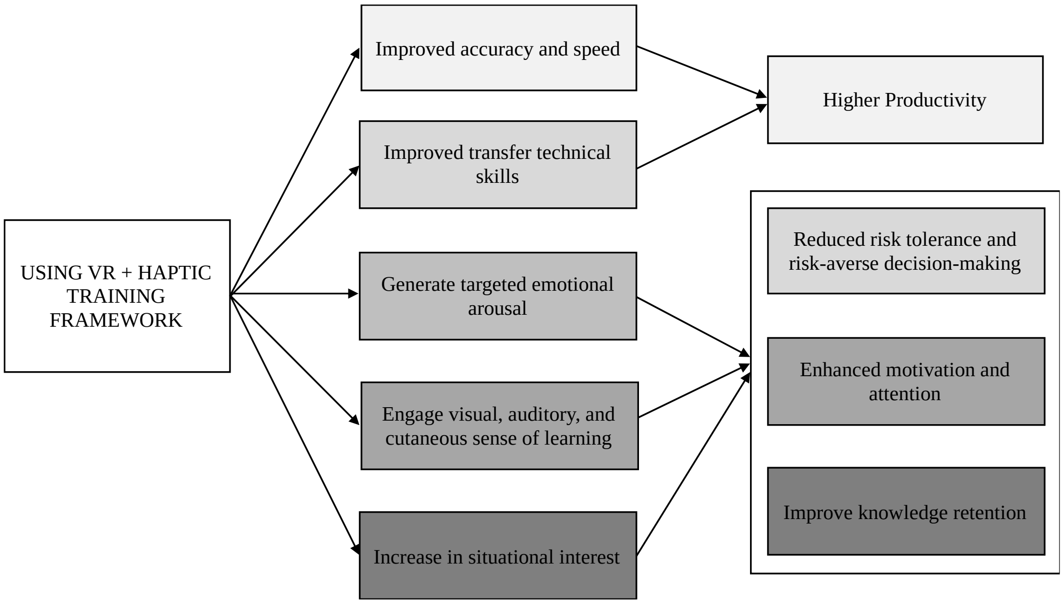

Figure 1: Pathways to potential gains from adopting VR + haptic training framework

From a psychological context, while researchers agree that VR and haptic technologies can be used to generate emotional arousal, there is uncertainty regarding their pervasive nature. In other words, it is unclear if these technologies generate more intense *and* sustained emotional experiences over the traditional media, and if those experiential emotions mediate learning and decision-making among adult learners. Such knowledge would not only benefit construction community, but also learning and psychology community as adult learners are often neglected and the learning agents in occupational training environment have not been rigorously examined.

There are indeed some practical challenges that need to be explored as well. The construction industry shows significant resistance when it comes to adopting and adapting to new technologies. It is not clear how often this type of training would need to be provided and how could it be integrated with current safety training methods such as Occupational Safety and Health Administration 10-hour training, safety inductions, and hazard checklist (e.g., jobsite hazard analysis) as it is possible that former may not effectively address each task and site-specific challenges. Finally, there is also no comprehensive study that could be identified to understand what challenges workers may have while interfacing with new and sophisticated technology. If these practical challenges are not addressed adequately, it could impede the industry adoption on a wide-scale, regardless of the proposed or empirically validated benefits.

4. CONCLUSION

While there has been significant research within the safety domain, safety training itself in the construction industry has hardly changed over the past few decades. It has not evolved to address the advancements in the field of adult learning, nor has it been very accepting of new technologies for various reasons (e.g., first costs, skepticism and reluctance due to lack of existing users, and scaling issues). These reasons have been published in industry reports (KPMG International 2016), however they have not been empirically validated by the research community. Restructuring the training programs from the ground up could address critical competency needed in the largest single-service industry in U.S., which is about to see an influx of new workers to address the crippling workforce shortages. The purpose of this paper was to highlight theoretical learning and behavioral gains that the industry could reap by adopting VR and haptic technology-based learning environments and also to identify key gaps in the current body of knowledge. Although VR based training with haptic feedback may require more upfront resources, the authors posit that workers who are given training in immersive experiential learning environments would be more productive, retain knowledge better, and make appropriate risk-averse decisions.

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