Exploring the Potential for Safety Training in VR to Generate Emotional Engagement and Situational Interest among Construction Workers

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Abstract: To improve its traditional safety training methods, the construction industry has started to adopt virtual reality (VR) to enhance workers' safety practices. Although preliminary research has shown promising results for the adoption of VR in safety training, there is a dearth of research on whether VR supports engagement [emotions and situational interest (SI)] among construction workers. Additionally, it is unclear if the potential improvements in engagement translate to learning achievements. This study sought to address this existing knowledge gap by assessing the impact of VR-based safety training (when adopted with traditional passive training and used as a tool to provide situated learning) on the conditions affecting learning—in this study, emotions and situational interest. The study used a quantitative quasi-experimental approach not only to evaluate how incorporating VR (and VR paired with haptic feedback) to a traditional passive training session affects these key conditions, but also to evaluate the effect of emotions and situational interest on the learning outcomes obtained from the experience. The study gathered data from 221 participants representing various sectors of the construction industry across the United States, including both on-site workers and construction managers. Parametric tests showed that VR-based safety training, as tested in this experiment, increased negative emotions and decreased positive emotions of participants, aligning with results from past studies. Findings indicated that the experience was effective at eliciting emotional arousal among participants. Results indicated a statistically significant increase in situational interest, including interest in the use of VR technology for construction safety trainings but did not have a statistically significant effect on maintained value-based situational interest (which is related to the perceived long-term value of the experience). Finally, results also showed that emotions and situational interest do not influence the learning outcome obtained from the experience. These results underscore the potential of VR-based safety training to significantly enhance situational interest and emotional responses; however, they also challenge the assumption that emotional engagement and situational interest directly enhance learning outcomes from a VR-based safety training module, as tested in this experiment. This research underscores VR's potential in safety training while highlighting the need for further exploration into how these technologies influence learning efficacy. **DOI: 10.1061/JCEMD4.COENG-16211.**

Practical Applications: This study provides critical insights for the use of virtual reality in construction safety training. While VR is often promoted to increase the engagement of learners who use it, the results of this study suggest there is more nuance to this claim. When combined with traditional safety training, VR was effective at sparking participants' interest and emotional reactions during the experience but did not necessarily lead to improved learning outcomes. This suggests that while VR can make safety training more compelling, it does not automatically result in better learning compared to traditional training. A modest relationship between interest and performance emerged only when all participants were analyzed together, suggesting the effect may be small and sensitive to variability in training context or delivery. Given the substantial investments associated with the use of VR technologies, these findings offer much-needed clarity for organizations by illustrating how VR can be meaningfully integrated into safety training programs to enhance learning outcomes. Construction companies may choose to leverage VR to increase interest in safety training, but it should be carefully designed and potentially paired with other approaches to ensure participants meet the desired learning outcomes. This study suggests the need for additional research that further explores the role of VR in a variety of construction sectors, along with studies that focus on other factors affecting learning, such as motivation and prior experience.

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Introduction

Traditional classroom-style safety training is often perceived as monotonous, presenting information in a way that can be difficult for adult learners to retain (Knowles et al. 2014). Its standardized and sterile format frequently results in low engagement, failing to address diverse learning needs or motivate trainees effectively (Demirkesen and Arditi 2015; Namian et al. 2016). As a result, both practitioners and researchers are increasingly exploring emerging technologies to enhance the efficacy of conventional safety training programs. Innovations such as virtual reality (VR), augmented reality (AR), mixed reality (MR), and building information modeling (BIM) have been investigated as alternative platforms for safety training (Bosché et al. 2016; Knowles et al. 2014). Of these, VR has garnered significant attention as a promising future platform, enabling the simulation of hazardous work environments without exposing workers to real-world risks.

This study builds on existing research by examining whether VR can serve as an effective supplement to traditional safety training. While previous studies have primarily focused on the standalone efficacy of VR-based safety training, our investigation explores how integrating a VR experience after traditional training influences key conditions affecting learning, specifically emotional engagement and situational interest (SI). Generating these conditions has been shown to positively impact learning outcomes across various educational contexts (Chung et al. 2015; Linnenbrink-Garcia et al. 2010; Mayer 2009; Pekrun et al. 2002; Renninger et al. 2014; Schiefele 1991). Additionally, we evaluate whether heightened engagement and interest in the training environment correlate with improvements in hazard recognition, risk perception, risk tolerance, and safety-related decision making. In this study, engagement refers to the extent to which a trainee actively participates in the training experience, encompassing their interactions with people, activities, goals, values, and the learning environment (Skinner et al. 2009). In simpler terms, it reflects the effort a trainee invests in instructional tasks (Beder et al. 2006). These findings aim to provide guidance on the appropriate role of VR in enhancing safety training outcomes for construction workers.

Immersion has long been recognized as a critical factor in VR-based learning, with deeper immersion leading to more positive learning experiences and improved knowledge acquisition. This study extends prior research by examining the role of haptic feedback within the VR environment. While the use of haptic feedback has been supported in the context of VR training (Ye et al. 2023, 2024), its specific impact on emotional engagement and situational interest remains underexplored. Thus, this study addresses the following research question: Does the combination of VR training, traditional safety training, and haptic feedback enhance emotional engagement and situational interest? The results will provide insights into whether haptic feedback should be integrated into VR safety training programs to improve engagement and learning outcomes among construction workers.

Background

This study adopts the constructivist learning theory as its theoretical framework, positioning learning as an active process where learners construct their own knowledge (Christie and De Graaff 2017). This theory is well-suited to VR-based safety training, as it emphasizes situated learning, wherein having the learners directly involved in practice enhances their knowledge retention (Asad et al. 2022). In VR experiences, learners create subjective representations of reality, linking new information to prior knowledge (Dede 2008). Thus, it is reasonable to assume that VR supports constructivist learning by placing learners in authentic contexts by engaging them in realistic activities that deepen their connection with the learning material.

This study uses the situational awareness framework to assess learning outcomes. Tixier et al. (2014) applied this framework to safety context by breaking into three linear sequential components: (1) hazard recognition, (2) risk perception, and (3) risk tolerance. These components lead to decision making under risk. The objective of most safety training programs is to positively influence these components of situational awareness i.e., learning outcomes. Thus, the authors aim to examine if the VR-based learning experience can foster conditions for effective learning and whether those conditions improve learning outcomes. Emotions and situational interest were chosen as key conditions, which have been shown in learning literature as strongly correlated with improved learning outcomes (Fassbender et al. 2012; Pekrun 2006). Additionally, integral negative emotions have been linked with improved sensitivity toward risks within construction safety literature as well (Keller et al. 2006; Tixier et al. 2014).

Condition Affecting Learning: Emotions

Emotions are understood as multifaceted reactions that help individuals adapt to their surroundings (Oatley et al. 2006). Both integral and incidental emotional responses can enhance knowledge retention (Bradley et al. 1992; Brown and Kulik 1977; Cahill and McGaugh 1998), motivation (Bradley et al. 1992; Cahill and McGaugh 1998; Fassbender et al. 2012; Goetz et al. 2007; Pekrun 2006; Pekrun et al. 2002, 2009), and attention (Wang and Liao 2021) during learning. By experiencing emotional engagement within learning environments, learners can achieve learning objectives more rapidly and recall knowledge more readily (Chung et al. 2015; Mayer 2009). Positive emotions foster intrinsic motivation and creative thinking (Bless et al. 1996; Isen 2001), while negative emotions such as fear and anxiety can support detail-oriented problem solving (Pekrun et al. 2002; Turner and Schallert 2001). Emotions can also be a tool for conditioning risk-taking behavior (Loewenstein et al. 2001). Individuals utilize emotional cues and feedback to shape their values and preferences, thereby affecting their judgments and decisions (Lerner and Keltner 2000; Slovic et al. 2002). While positive emotions can foster both risk-prone and risk-averse behaviors, negative emotions are typically linked only with the latter. In safety, researchers have sought to generate contextually apropos negative emotions (i.e., reducing the positive appraisal of risks) during safety trainings to regulate risk-prone behaviors (e.g., sensation seeking and improvisation (Bhandari et al. 2019; Tixier et al. 2014).

However, there are still gaps in the body of knowledge. While previous studies have shown VR can generate and alter the emotional state of individuals (Patil et al. 2023), those findings lack external validity, and therefore cannot be generalized for construction workers. Additionally, the impact of emotional arousal on safety skills within the safety training context has only used inferential evidence (e.g., Bhandari et al. 2019) thus far. The true nature of the relationship between learning antecedents and learning outcomes within an occupational VR-based learning experience with adult learners remains underexplored.

Thus, this study aims to determine to what extent, if at all, a combined learning experience in VR environment paired with traditional safety training modality increases the emotional arousal among construction workers. Additionally, this study also examines if the potential emotional arousal facilitated improved learning outcomes (i.e., hazard recognition performance, risk perception, risk tolerance, and safe decision making). These fundamental questions will not only clarify the true effectiveness of VR-based learning experiences but also determine whether emotional responses contribute toimproved learning outcomes or are merely associated with increased engagement.

Condition Affecting Learning: Situational Interest

The collective body of knowledge indicates that, like emotions, situational interest may be a primary driver of the learning process and long-term independent learning (Harackiewicz et al. 2000). Situational interest is defined as a state of desire to know or learn about a topic that is generated during the learning experience itself (Alexander and Jetton 1996; Hidi and Baird 1986; Hidi and Renninger 2006; Krapp and Fink 1992; Silvia 2001; Hidi 1990).

According to Linnenbrink-Garcia et al. (2010), situational interest consists of both an attentional and emotional reaction to learning, which can be differentiated into two forms: triggered-SI and maintained-SI (Dewey and Wheeler 1913; Hidi and Baird 1986; Hidi and Renninger 2006; Krapp 2002; Mitchell 1993). Triggered-SI is generated if a learner experiences emotional engagement during the learning experience and is the initiation of interest (Hidi 2001; Hidi and Renninger 2006; Hidi and Harackiewicz 2000). Maintained-SI refers to a more involved, deeper form of situational interest in which individuals begin to forge a meaningful connection with the content of the material and realize its deeper significance (Dewey and Wheeler 1913; Hidi 2001; Linnenbrink-Garcia et al. 2010; Mitchell 1993). Triggered-SI is typically a precursor to maintained-SI. Linnenbrink-Garcia et al. (2010) also deconstructed maintained-SI into feeling-based and value-based. Maintained-SI feeling refers to the extent to which the material itself was enjoyable and engaging, whereas maintained-SI value refers to whether the material was viewed as important and valuable (Linnenbrink-Garcia et al. 2010). In other words, maintained-SI value is a deeper form of interest.

Makransky and Lilleholt (2018) and Radianti et al. (2020) suggested that VR can increase the participant engagement, and consequently the lesson learned is greater and more lasting. Previous studies have not explored to what extent, if at all, VR-based learning experience paired with traditional training generates situational interest among construction workers. Typical training programs can generate negative appraisal toward safety in some cases (Haslam et al. 2005). This study aims to establish whether or not VR generates the desired interest among construction workers to complement existing training modalities.

Using Virtual Reality to Improve Safety Skills

Although research studies have found VR to be effective in enhancing hazard recognition (Jeelani et al. 2020; Noghabaei and Han 2020; Scorgie et al. 2024) and risk assessment (Tixier et al. 2014; Yoo et al. 2023) skills of construction workers, there is no clear understanding about how these benefits are derived. This means that, from a learning perspective, there is a lack of evidence of how, if at all, VR affects key antecedents to learning and consequently, whether those antecedents impact the learning outcomes in any meaningful way. The exploration of this concept is essential to the understanding of how VR should be designed to enhance learning, as it could provide insight to the factors of a VR simulation that influence participants to make the most out of the experience. If these factors are explored, they can be targeted by software developers, researchers, and industry professionals to design and adopt VR simulations that maximize educational outcomes. Thus, this study aimed to examine how implementing VR (when adopted as a means to provide situated learning grounded on hazard recognition skills of construction works) with a traditional safety training session affects the learning outcome obtained by exploring two key antecedents of learning: emotions and situational interest.

Haptic Feedback in VR

Within the context of immersive technology, haptic refers to devices that enhance computer-simulated experiences by recreating touch sensations, and providing an enriched interface between humans and computers (Robles-De-La-Torre 2010; Rakkolainen et al. 2021). These devices are increasingly combined with VR, enhancing the transfer of virtual skills to real-world applications and fostering stronger connections to the subject matter (Jones et al. 2006). This effect is attributed to the cutaneous and kinesthetic sensations provided by VR and haptic feedback, which support increases in working memory capacity (McGee 2002; Kiili 2005) while generating curiosity and interest (Jones et al. 2003).

Though both VR and haptic feedback have independently been shown to elicit emotional responses, curiosity, and engagement (Gorini et al. 2011; Riva et al. 2012; Smith and MacLean 2007), their combined impact on learning during safety trainings remains unclear. From the learning perspective, it is unclear (1) if the two technologies in their aggregate create intensified experiences and (2) how these experiences affect the learning outcome obtained among construction workers. This study explores whether combining haptic feedback with VR training, in addition to traditional training, enhances emotional responses and situational interest among construction workers, testing the null hypothesis that no significant effect occurs.

Research Methods

This study examines the extent to which providing construction workers with a learning experience in a VR environment alongside traditional safety training influences their emotional arousal and situational interest and whether these conditions lead to improved learning. Subsequently, the authors also examine whether the change in emotional arousal and/or situational interest is correlated with the learning achievements (i.e., improved hazard recognition performance, risk perception, risk tolerance, and safety-related decisions) of construction workers. Finally, this study isolates and examines the impact of using haptic feedback within the VR environment to generate physiological and psychological responses associated with improved learning. To address these objectives, a field-based quasi-experiment was designed that measured the change in emotional arousal, situational interest, and the aforementioned safety skills of construction workers before and after a training intervention. The following sections elaborate on the experimental protocol shown in Fig. 1.

Prerecorded Video Training

Traditional safety training programs typically include one-way delivery of information. Either a facilitator delivers information in-person, or a prerecorded video is shown to workers with pertinent

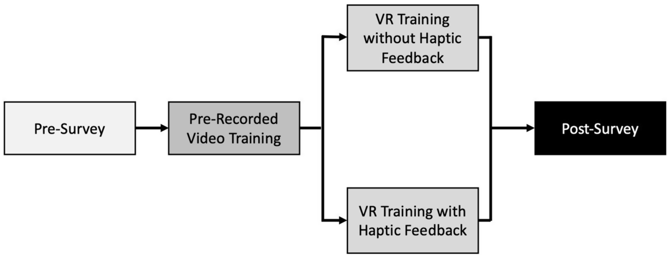

Fig. 1. Experimental protocol.

information (Alsharef et al. 2020). While many studies have criticized this approach to safety training as ineffective in that it could lead to apathetic or negative appraisal toward safe practices (Haslam et al. 2005), it remains highly operationalizable without being a resource intensive option for most organizations. Given the size of the workforce within the industry, disparate trades and working conditions, organizational barriers, and unique individual differences (e.g., educational background of trainers and trainees), it is unlikely that alternative approaches to deliver safety training to the workforce would *completely* replace the existing framework anytime soon. Therefore, it is pertinent to study how proposed alternative approaches in literature supplement traditional approaches to safety training for a true reflection of their efficacy. This study examines the efficacy of a learning experience that combines video-based training with training in VR environment.

A prerecorded video training intervention was selected to minimize any confounding effects that may emerge from nonstandardized delivery of training. Consistent delivery of training was key as the study seeks to measure the changes in physiological and psychological antecedents to improved learning. The training consisted of a detailed explanation on the principles of energy-based hazard recognition. This concept was adopted because it has shown to significantly enhance hazard recognition abilities (Albert et al. 2017) of workers, with findings indicating an average improvement in hazard recognition performance of about 30% (Albert et al. 2014a). It instructs participants to define hazards as energy sources and utilize the energy wheel as a mnemonic device in identifying all relevant hazards. For detailed information on the training content, readers are directed to the previous studies that validated this training program (e.g., Albert et al. 2014a, b; Hallowell 2021).

Virtual Environment

The VR environment simulated a pipeline welding process. The dynamic simulation showed various weld shacks being lifted by side booms and being placed over the section of pipe that is to be welded. Participants explored the VR environment to identify hazards present in the construction scene (Fig. 2). When participants completed the hazard identification activity, they navigated to a virtual avatar to report out on hazards identified. When hazards went undetected, participants would see (Fig. 3), hear, and feel through haptic technologies (Fig. 4) a virtual representation of the resultant safety incident.

An expert panel of six industry professionals provided guidance on how to improve the realism of the jobsite (e.g., equipment, personnel, traffic, tasks, landscapes), thereby enhancing the ecological validity of the experiment. The authors adhered to expert selection guidance provided in Hallowell and Gambatese (2010). These were industry experts in the oil, gas, and refinery sector with a cumulative experience in safety of over 100 years. In the past, these experts had also served on several national-level research panels focused on improving safety on jobsites. In this project, experts were tasked with ensuring realism and accuracy in the virtual environment based on their extensive field experience. The virtual environment was developed using Unity Game Engine and deployed via HTC Vive Pro VR headset.

Fig. 2. Shack assembly construction scene.

Special attention was paid to enhance immersion of participants inside the VR environment to support improved learning outcomes (Patil et al. 2023; Yoo et al. 2023). To achieve this objective, the simulation included construction sounds (e.g., equipment noises, worker conversations, traffic commotion), terrain and climate variability, vegetation, and social interactions between virtual avatars. Additionally, the movements of virtual avatars were defined using Rokoko motion capture suits to produce realistic virtual avatar interactions and movements.

Learning Experience in VR

The virtual intervention started with a training session, which involved practicing basic movements such as walking, turning, and

Fig. 3. Undetected accident occurring.

Fig. 4. Participant in VR Equipment. (Image by Steven Ayer.)

taking photos within a neutral virtual environment (unrelated to construction to prevent anchoring effects), to minimize the impact of extraneous cognitive load (Sweller et al. 1998). Once participants verbally acknowledged they were acclimated to the VR, they were given access to enter the construction environment.

In the simulation of the construction worksite, participants were asked to complete a targeted learning exercise. They were asked to conduct a safety audit, which included walking the site, observing the work, taking pictures of simulated hazards, and reporting back to the field supervisor when finished. The pictures were taken by participants within the virtual environment using a simulated tablet that their avatar would be carrying. Participants were given a maximum of 30 min to complete their safety audit and report to the field supervisor.

Upon connecting with the field supervisor, the participants would witness an accident that results in serious injury or fatality. Two accidents were designed in consultation with the industry experts: *a welding shack falling on a worker when the cables lifting the shack snap*; and *a heavy mobile equipment crushing a worker that entered in its line of fire and operator's blind spot*. Both accidents happen to a virtual avatar, not the participant, who remained a passive observer of the events unfolding. The decision to have the accident happen to a virtual avatar rather than the participant was made for psychological safety and ethical considerations—an accident directed at the participant could induce distress, anxiety, or unintended cognitive load. By having the accident happen to an avatar, participants were able to engage in the observation and analysis of hazardous scenarios without experiencing undue emotional strain. The participants would see only one accident, and selection of the accident simulation was randomized. Bhandari and Hallowell (2017) showed that realistic injury demonstrations elicit contextually apropos negative emotional responses among construction workers, which have been linked to enhanced risk perception and decreased risk tolerance (Keller et al. 2006; Loewenstein et al. 2001; Tixier et al. 2014).

In addition to psychological priming, the accident simulations were also aimed at providing targeted learning. Specifically, the simulation would pause immediately after the virtual avatar contacts the hazard (i.e., falling shack or moving equipment) without showing the aftermath (e.g., severity of incident) to the participant. During the pause, participants were asked to engage in a reflective dialogue which was led by a facilitator, who posed as the site field-supervisor. The facilitator's role was to probe at the participant's thinking during the VR experience using a structured protocol without disrupting the immersion or realism of the environment. This step promotes reflective learning wherein participants were asked questions that direct them to reflect on the accident (e.g., what just happened?). In alignment with adult learning principles, this approach encouraged learners to identify their own knowledge gaps, assess their understanding of safety procedures, and directly apply the insights gained to enhance their workplace practices (Garrison 1997).

Participants were randomly divided into VR+Haptic and VR-Only groups where the former included haptic feedback during the virtual simulation, and the latter did not. In the VR+Haptic group, synchronized vibrations from wearable haptic devices were triggered only when a participant actively witnessed an accident. This kinesthetic feedback was designed to enhance immersion by engaging additional senses, specifically the sense of touch, and replicate the physical sensations of an accident on a jobsite (e.g., the vibration caused by heavy equipment hitting the ground). This feedback was not intended to necessarily replicate the physical sensations from an accident but rather to simulate the embodied stress response that witnesses could experience in real life—such as a jolt of shock, a sudden increase in heart rate, or constrained breathing (Caserman et al. 2024). By engaging the sense of touch, the haptic layer deepened immersion and approximated the physiological and psychological effects of observing a traumatic incident on site. Haptic sensations were incorporated via bHaptics equipment, managed by bHaptics Player software. The wearable haptic feedback hardware comprised the TactSuit X40 (for torso), the TactVisor (for facial feedback), and Tactosy (for both hands) enriching the virtual reality experience with vibrational feedback across multiple body regions.

Assessments

The experiment utilized an A + B experimental design with a presurvey and postsurvey, which was administered after the video training and again after the VR experience, to measure changes in safety skills, emotional arousal, and situational interest. The surveys, described below, were self-reported in nature and validated in previous studies. The presurvey and postsurveys were the same, except that the postexperiment included questions that captured demographic information of participants (see Table 1). In addition to the surveys, the authors also measured the physiological responses during the VR experience to objectively determine the level of emotional arousal among participants.

Measuring Safety Skills

The surveys measured three critical safety skills required of construction workers: ability to identify hazards, assess the risk associated, determine tolerance toward the risk, and make a safety-related decision. Presurveys and postsurveys included one unique photograph, each depicting active construction work. Each presurvey and postsurvey included a unique photograph depicting active construction work. While the photographs did not contain the same number of hazards, they were systematically counterbalanced across the presurveys and postsurveys to neutralize any potential bias due to photo complexity or content (Albert et al. 2014b, 2020; Han et al. 2020; Hardison and Gray 2021). Participants were instructed to observe the depicted work scenario and identify all possible hazards. The authors took the number of hazards correctly identified by the participants and divided it by the total number of hazards in photograph to give each participant a hazard performance score. The subsequent questions–*how dangerous is the work environment as shown in the picture?* and *how comfortable would you be working in this environment as shown in the picture?*–measured participants' risk perception and risk tolerance, respectively. They were asked to respond to both questions on a Likert Scale (1–5), where 1 represented "Not at all," and 5 represented "Extremely." The final question required participants to make a safety-related decision by indicating their willingness to stop work on a scale of 1–5, where 1 represented "Definitely not," and 5 represented "Definitely yes." This self-report approach to ascertaining safety skills of construction workers has been validated in previous studies (e.g., Albert et al. 2014a, b; Bhandari et al. 2020).

Measuring Emotional Arousal

To measure the change in emotional states of workers, an emotional inventory survey was deployed which asked participants to report the intensity with which they experienced 16 distinct emotions on a 9-point Likert scale (Gross and Levenson 1995; Bhandari and Hallowell 2017). This approach captures the subjective assessment of each individual on their emotional state without introducing demand characteristics.

In addition to the subjective measure, participants were also fitted with a galvanic skin response (GSR) sensor that objectively measured their emotional arousal within the VR environment. It measures skin conductance by monitoring the changes in sweat gland activity that are reflective of emotional arousal (Farnsworth 2018).

Table 1. Demographic distribution (n = 221)

Demographic dimensions	Subcategories	Number of participants
Years of experience within the construction industry	0–10 years	133
	10–20 years	41
	20–30 years	23
	30–40 years	20
	40–50 years	3
	50–60 years	1
Witnessed injury	Has not witnessed an injury	93
	Minor (first-aid injury)	11
	Moderate (medical case but not life-threatening)	32
	Serious (lost worktime to recover from injury)	49
	Critical (disabling or fatal)	36
	Decline to respond	0
Been injured	Has not been injured	151
	Minor (first-aid injury)	21
	Moderate (medical case but not life-threatening)	20
	Serious (lost worktime to recover from injury)	25
	Critical (disabling)	1
	Decline to respond	3
Age	10–20 years	8
	20–30 years	89
	30–40 years	55
	40–50 years	39
	50–60 years	25
	60–70 years	5
Gender	Male	181
	Female	40
Role	Site-leadership/management	109
	Field (any trade)	112
Education	High School and below	84
	Some college (inc. associate degree or community college)	31
	Bachelor's degree and above	97
	Trade/apprenticeship school	9
Ethnicity	White	128
	Black or African American	23
	American Indian or Alaska Native	2
	Asian	6
	Native Hawaiian or Pacific Islander	1
	Hispanic/LatinX	49
	Multiracial	7
	Decline to respond	5
Language in which the training was conducted	English	203
	Spanish	18

Essentially, increased stress or emotional excitement raises sweat gland activity, resulting in greater skin conductance. The GSR device consisted of a wearable hardware device which was secured on the participant's left hand, with nodes on the middle and ring fingers, connected to a wrist-worn device that recorded data onto an SD card. Changes in skin conductance are detected by the GSR sensor and reported in microsiemens (uS) at millisecond intervals. GSR is widely used as an index of physiological arousal in response to various stimuli (Boucsein 2012; Cacioppo et al. 2007), and the authors used it to confirm whether the VR simulation effectively induced physiological arousal or not.

Measuring Situational Interest

Researchers have employed self-report surveys to assess situational interest as a means of evaluating the effectiveness of innovative teaching strategies (Ainley and Ainley 2011; Kang et al. 2010; Linnenbrink-Garcia et al. 2010; Schiefele 1991). Thus, this study used an adaptation of Linnenbrink-Garcia et al. (2010)'s three-component situational interest model (i.e., triggered, maintained feeling-based, and maintained value-based). The survey consisted of 12 statements, with four statements for each component of the situational interest model as validated in Bhandari et al. (2019) for safety training in occupational context. Participants were asked to report the extent to which they agreed with the statements on a 5-point Likert Scale, where 1 represented "strongly disagree," and 5 represented "strongly agree."

The authors also included two additional statements to evaluate the extent to which learning experience generated interest in the use of VR technology for construction safety training. These questions were added at the end of the 12 statements to avoid introducing any confounding effects.

Participant Recruitment

A total of 221 construction industry workers participated in the study. This study was conducted on construction sites in job trailers to enhance the ecological validity of the learning experience. Additionally, participants were recruited from different backgrounds to enhance the external validity of the findings reported below. Participants from all industry sectors, such as commercial and infrastructure projects, oil and gas, and power generation and distribution, were recruited. Participants from different trades, years of experience, and role (i.e., leadership/managers versus field workers) across the industry were recruited for this experiment. A posthoc power analysis confirmed the adequacy of the sample: assuming a medium effect size (Cohen's $d = 0.5$), an alpha level of 0.05, and power of 0.80, a minimum of 128 participants (64 per group: VR-Only and VR+Haptic) was required for a between-subjects comparison. The achieved sample size exceeded this threshold, indicating sufficient power to detect moderate effects. Table 1 provides a summary of the demographic distribution of participants from this study.

The training was offered in both English (n = 203) and Spanish (n = 18), allowing participants to select their preferred language. A native Spanish speaker administered the training to ensure accurate communication and a culturally relevant experience for Spanish-speaking participants. All survey materials were translated by a bilingual speaker, and semantic equivalence was established to maintain consistency in meaning and intent across languages (Van de Vijver and Leung 2021). The experiment protocol adopted (see Fig. 1) did not permit the authors to include a control group (i.e., participants that received no VR experience). In a field experiment, the authors elected to ensure that each worker participating received training that would be potentially valuable. This limits the authors' ability to make causal conclusions. Additionally, as with any field-based experiment, the authors had limited control over the environment, which introduces internal validity concerns. To minimize external confounding effects, the following mitigation measures were taken: facilitator maintained a neutral demeanor to avoid influencing participants' emotional states, scripted facilitation by the same individual for all training sessions, prerecorded video-based training for standardization, and bilingual training and assessments for participants.

Results

The distribution of the sample means is expected to approximate a normal distribution per central limit theorem (Field 2013; Mascha and Vetter 2018), allowing for the use of parametric statistical tests. While the data collected from the emotional inventory and situational interest surveys were based on Likert scales (5- and 9-point), prior research has demonstrated that parametric tests such as paired t-tests remain robust for ordinal data, especially when sample sizes are moderate to large (Norman 2010). Thus, it was deemed to be appropriate to apply t-tests for pre-post comparisons in these survey measures. Outcomes were considered statistically significant if they met or exceeded a 95% confidence level, corresponding to a p-value of less than 0.05.

Changes in Safety Skills

Findings related to changes in participants' safety skills—specifically hazard recognition, risk perception, risk tolerance, and safety-related decision making—are reported in detail in Lopez et al. (2025). Briefly, while the combination of passive video training and VR exposure led to a statistically significant improvement in hazard recognition from baseline, participants' performance declined significantly ($p < 0.05$) following the VR-based training. This decline was unexpected and may be attributed to the immersive, novel, and emotionally provocative nature of the VR environment, which may have temporarily disrupted participants' ability to focus on hazard identification tasks. No statistically significant changes ($p > 0.05$) were observed in participants' risk perception, risk tolerance, or willingness to stop work. These findings suggest that while VR has potential to engage learners, its effectiveness in reinforcing certain safety competencies—particularly in unguided or high-immersion contexts—may be limited (Lopez et al. 2025).

Was There a Statistically Significant Emotional Impact on the Trainees due to the Training Intervention?

To examine possible emotional changes, a paired (unbalanced) sample t-test was used, as it connects presurvey and postsurvey responses of individual participants (Ross 2018). Table 2 presents the findings across the two experimental groups (VR with Haptic Feedback and VR without Haptic Feedback). A total of 38 participants were dropped from the analysis due to incomplete responses to the emotional inventory portion of the survey.

Findings show that both groups experienced a statistically significant change in their emotional state immediately after the learning experience. While it is not to be causally attributed to the learning experience, the associative evidence suggests that learning experience that pairs VR with prerecorded video-based training is emotionally evocative. There is a statistically significant increase in amusement, guilt, and surprise *and* a decline in happiness and love among both groups. Additionally, the VR experience with haptic feedback generated statistically significant increase in anger, anxiety, fear, shame, and unhappiness while VR experience with no haptic feedback saw a decline in contempt, joy, pride, and an increase in confusion. These results demonstrate the effectiveness of VR (with or without haptic feedback) in eliciting strong emotional responses, which is crucial for immersive learning experiences. Across the board, the learning experience elicited contextually apropos and desired negative emotions that are linked with risk-averse appraisals (Yuen and Lee 2003). Cohen's d effect sizes were calculated and reported in Table 2 to indicate the magnitude of emotional change experienced by participants; values above 0.8 reflect large effects, underscoring the emotional impact of the VR training intervention (Lakens 2013).

Before analyzing the physiological data collected using the GSR, a low-pass filter was applied to remove common GSR artifacts and drift, which often introduce noise into the data, following recommendations by Boucsein (2012). This step was executed using the Consensys software by Shimmer Sensing, the same platform used for GSR data acquisition (Shimmer 2021). The GSR data were timestamped to mark three pivotal moments for participants within the VR environment: (1) entering and exploring the simulation; (2) beginning of the accident; and (3) postaccident conversation with the facilitator. On average, participants spent approximately 9 min exploring the virtual jobsite, the simulation of the accident lasted approximately 0.33 min, and the follow-up conversation spanned an average of 2.60 min.

Although the GSR device was worn by all participants, the data from only 95 participants were usable for analysis, due to technical errors in other cases from the GSR sensor which led to corrupted or

Table 2. Change in emotions

	VR-only			VR with haptic feedback		
	n = 98			n = 85		
Emotion	Percent change (%)	P-value	Effect Size	Percent change (%)	P-value	Effect Size
Amusement	0.73	<0.001	0.31	1.42	<0.001	0.74
Anger	0.07	0.555	0.06	0.27	0.021	0.19
Anxiety	0.00	1.000	0.02	0.63	0.002	0.37
Confusion	0.69	0.003	0.33	0.27	0.126	0.23
Contempt	−0.32	0.010	−0.26	−0.02	0.900	−0.02
Disgust	0.04	0.675	0.07	0.21	0.091	0.18
Embarrassment	0.24	0.127	0.26	0.28	0.091	0.21
Fear	0.09	0.486	0.18	0.30	0.022	0.31
Guilt	0.43	0.013	0.29	0.45	0.006	0.33
Happiness	−0.71	<0.001	−0.34	−0.45	0.027	−0.26
Interest	−0.07	0.715	−0.05	−0.07	0.717	0.02
Joy	−0.58	0.001	−0.37	−0.25	0.224	−0.16
Love	−0.46	0.011	−0.34	−0.33	0.022	−0.27
Pride	−0.61	<0.001	−0.41	−0.40	0.064	−0.23
Sadness	0.13	0.523	0.10	0.35	0.066	0.22
Shame	0.18	0.355	0.15	0.53	0.002	0.36
Surprise	1.68	<0.001	0.57	2.69	<0.001	1.02
Unhappiness	−0.02	0.903	0.07	0.34	0.025	0.29

Table 3. Changes in emotional arousal

	VR–only			VR with haptic feedback		
	n = 52			n = 43		
Time	Mean conductance (uS)	Change in mean conductance	P-value	Mean conductance (uS)	Change in mean conductance	P-value
Explore virtual jobsite	3.73	—	—	3.23	—	—
Witness the virtual accident	4.13	0.397	0.005	3.55	0.322	0.008
Conversation about the witnessed accident	4.34	0.205	0.039	3.90	0.352	0.043

incomplete data files. A paired t-test analysis was performed to determine whether there was a statistically significant change in skin conductance levels (measured in microsiemens, uS) among participants across the two experimental groups.

Table 3 revealed a statistically significant increase in mean conductance levels upon witnessing the virtual accident and during the follow-up conversation in both VR groups. Specifically, witnessing the virtual accident elicited a notable increase in emotional arousal, with mean conductance levels significantly rising in both groups (p-value <0.01 for both groups). The significant increase in mean conductance levels upon the accident's simulation confirms that the VR learning experience designed in this study can increase engagement levels among participants to such a degree that it leads to a change in their physiological state. It is notable that the situated learning component when the facilitator asked reflective questions of trainees increased the conductance levels (i.e., arousal) among participants. This is striking because the increase in arousal was registered on top of the elevated level due to witnessing of the accident. Both the subjective and objective results allow the authors to confirm that the learning experience designed in this study increased emotional engagement among trainees.

Was There a Statistically Significant Increase in Situational Interest among Trainees due to the Training Intervention?

To evaluate the changes in situational interest from baseline (Assessment 1) to post-VR (Assessment 2), a paired sample t-test was used. The obtained results, for both experimental groups, are shown in Table 4 across each dimension of situational interest and overall situational interest. Effect sizes (Cohen's *d*) are also reported to indicate the magnitude of change across each dimension.

Results showed a statistically significant increase in overall situational interest and across all of its components, including interest in technology, with the exception of maintained value-based interest. These results revealed that the experimental protocol enhanced the immediate environment-driven interest (i.e., triggered situational interest), improved worker's interest on the use of technology for construction safety trainings, increased the positive effect toward construction safety trainings (i.e., maintained feeling-based), and enriched overall interest in construction safety trainings. The lack of value-based interest indicates there is room for improvement in establishing the relevance of such training for workers.

Examining the Relationship between Change in Safety Skills, Emotional Arousal, and Situational Interest

Principal component analysis (PCA) was performed on the 18 discrete emotions from the self-report survey to reduce the dimensionality. It was deemed not optimal to examine all discrete emotions independently as it would inflate Type 1 error. PCA is a common analytical technique employed on high-dimensional data to reduce possible multicollinearity issues (Joliffe 1986). Here the authors aimed to capture highly correlated emotions and cluster them as new independent variables.

Prior to conducting the PCA, the data set was split into the two experimental groups: VR-Only and VR with Haptic Feedback. This allowed the authors to isolate the impact of haptic feedback in the subsequent analysis. To avoid sacrificing sample size roboustness, the *k*-nearest neighbor (kNN) imputation method was applied to address missing data for the 38 participants that had incomplete responses. This technique, as detailed in Batista and Monard (2002), identifies '*k*' closest variables to estimate missing data using a weighted average (Liao et al. 2014). Previous studies have validated kNN's effectiveness, highlighting its robustness and precision in processing similar data sets (Troyanskaya et al. 2001). The application of the technique allowed for complete data sets, consisting of 100 participants in the VR with Haptic Feedback group and 121 participants in the VR-Only group.

For PCA application, it is recommended to have at least 10 observations for each independent variable (Comrey and Lee 2013; Tabachnick and Fidell 2007), and the sample size should be at least five times larger than the number of independent variables (Hatcher 1994). Both experimental groups met these requirements. Direct oblimin technique was used to allow the factors to correlate (Tabachnick and Fidell 2007). Following the recommendations from Norman and Streiner (2008), for the *VR-Only group*, *Anxiety* (0.66), *Confusion* (0.66), *Love* (0.69), *Pride* (0.69), and *Surprise* (0.32) emerged with

Table 4. Change in situational interest

	VR-only			VR with haptic feedback		
	(n = 121)			(n = 100)		
Type of situational interest	Mean percent change (%)	P-value	Effect size	Mean percent change (%)	P-value	Effect size
Triggered	4.21	<0.001	0.34	2.90	0.046	0.20
Maintained feeling-based	3.76	<0.001	0.33	2.50	0.048	0.20
Maintained value-based	1.16	0.213	0.11	0.25	0.822	0.02
Interest in technology	5.79	<0.001	0.33	7.70	<0.001	0.51
Overall	3.44	<0.001	0.33	2.72	0.017	0.24

individual sampling adequacy scores of less than 0.7; thus, these emotions were removed from the data set. Similarly, for the *VR with Haptic Feedback group*, *Amusement (0.56), Contempt* (0.57), *Happiness* (0.67), *Love* (0.62), *Interest* (0.67), *Pride* (0.69), and *Surprise (0.64)* were removed from the data set. Once these emotions were removed, both data sets passed the Kaiser–Meyer–Olkin (KMO) test for global sampling adequacy and the Bartlett's test of sphericity (p-value <0.001), with no individual sampling adequacy score less than 0.7, indicating there is a strong relationship between variables proposed for PCA testing. The determinant of the correlation matrices suggested there were no singularity or multicollinearity issues on the data sets as well (Field et al. 2012).

A three-component (or factor) model was selected for the VR-Only group and a two-component model was selected for the VR with Haptic Feedback group. This decision was influenced by Kaiser's criteria, which advocate for retaining components with an eigenvalue exceeding 1 (Tabachnick and Fidell 2007). *Embarrassment* and *Sadness* were dropped from VR-Only group because they had communality scores below 0.2 (Child 2006). The three-component model explained 63.8% of the variability of the original VR-Only group data set, and the two-component model explained 57.0% for the VR with Haptic Feedback group. The resulting pattern matrices are shown in Tables 5 and 6, which showcase the factor loadings for each individual emotion across the two experimental groups.

Multiple linear regression was performed to examine how changes in emotions and situational interest impact change in situational awareness (i.e., hazard recognition performance, risk perception, risk tolerance, and safety-related decisions). When analyzed across the full data set ($n = 221$), a linear regression revealed a statistically significant relationship between overall situational interest and hazard recognition performance [F (1, 219) = 5.32, $p = 0.02$]. Although modest in size, this finding suggests that increased situational interest was associated with higher hazard recognition scores when accounting for the full sample. For VR-Only training experience, the analysis revealed that neither change in overall situational interest [F (1, 116) = 0.04; p = 0.84] nor change in PC1 [F (1, 116) = 0.05; p = 0.81], PC2 [F (1, 116) = 0.02; p = 0.89], or PC3 [F (1, 116) = 0.03; p = 0.91] showed any statistically significant relationship with *hazard recognition performance*. Only PC3 [F (1, 116) = 4.07; p = 0.046] showed a marginally statistically significant and negative relationship with change in *risk perception*. Change in overall situational interest [F (1, 116) = 0.04; p = 0.84], PC1 [F (1, 116) = 0.04; p = 0.84], and PC2 [F (1, 116) = 0.04; p = 0.84] did not show any statistically significant relationships with change in *risk perception*. No statistically significant relationships were observed between change in situational interest [F (1, 116) = 0.22; p = 0.64], PC1 [F (1, 116) = 1.06; p = 0.31], PC2 [F (1, 116) = 0.47; p = 0.49], and PC3 [F (1, 116) = 0.22; p = 0.18] with change in *risk tolerance*. The statistical significance of relationship between change in situational interest [F (1, 116) = 0.01; p = 0.92], PC1 [F (1, 116) = 1.37; p = 0.24], PC2 [F (1, 116) = 0.12; p = 0.73], and PC3 [F (1, 116) = 0.95; p = 0.33] and *safety decisions* was also the same. In summary, besides the negative relationship between PC3 and risk perception, the results did not provide any evidence linking increased emotional engagement and interest with change in learning outcomes of construction workers for VR-Only training group.

Table 5. Factor loadings for VR-only experimental group

Emotions	PC1	PC2	PC3
Amusement	0.250	−0.361	0.450
Anger	−0.253	−0.167	0.373
Contempt	−0.201	−0.400	−0.215
Disgust	−0.313	−0.417	−0.211
Fear	−0.230	−0.200	−0.481
Guilt	−0.335	0.005	0.465
Happiness	0.331	−0.400	0.036
Interest	0.312	−0.272	0.079
Joy	0.367	−0.307	0.010
Shame	−0.351	0.004	0.333
Unhappiness	−0.325	−0.375	0.020

Table 6. Factor loadings for VR with haptic feedback experimental group

Emotion	PC1	PC2
Anger	−0.299	0.329
Anxiety	−0.296	0.289
Confusion	−0.246	0.494
Disgust	−0.239	0.228
Embarrassment	−0.293	0.255
Fear	−0.275	−0.268
Guilt	−0.347	−0.292
Joy	0.223	0.406
Sadness	−0.351	−0.120
Shame	−0.337	−0.328
Unhappiness	−0.370	−0.044

Results were nearly the same for VR with Haptic Feedback Training group. When considering the relationship between change in hazard recognition and change in situational interest [F (1, 96) = 0.04; p = 0.84], PC1 [F (1, 96) = 0.17; p = 0.69], and PC2 [F (1, 96) = 0.64; p = 0.42], there were no statistically significant relationships. The analysis showed no statistically significant relationship between change in risk perception and the change in situational interest [F (1, 96) = 0.35; p = 0.55], PC1 [F (1, 96) = 0.65; p = 0.42], and PC2 [F (1, 96) = 0.66; p = 0.42]. Similarly, change in risk tolerance showed no statistically significant relationships with change in situational interest [F (1, 96) = 0.37; p = 0.55], PC1 [F (1, 96) = 0.49; p = 0.48], and PC2 [F (1, 96) = 0.22; p = 0.64]. Finally, change in situational interest [F (1, 96) = 0.02; p = 0.90], PC1 [F (1, 96) = 0.20; p = 0.66], and PC2 [F (1, 96) = 0.17; p = 0.68] did not have any meaningful associations with safety decisions. This allows the authors to posit that no clear evidence exists demonstrating that engagement generated from VR-based training experience (with or without haptic feedback) impacts the eventual safety-related learning achievements among adult learners.

Discussion

The results from this study affirm the efficacy of VR-based learning environments (with and without haptic feedback) in evoking a strong targeted emotional response and interest among learners. A number of factors within the learning environment (e.g., novelty, animated pedagogical agents, and/or reflective questions) may have contributed to this increase in situational interest and emotional arousal. Although the research design does not isolate the efficacy of individual conditions affecting learning, it is reasonable to conclude that any future training programs that mirror the design and delivery of the VR-based training experience presented here can expect similar outcomes. The results also underscore the validity of using adult learning principles included in the learning experience to generate engagement across a diverse population of learners in occupational settings.

An increase in emotional arousal was demonstrated in the study through self-reported and physiological data. The ”dread factor”

(Burke et al. 2011) introduced in this training through the simulation of an accident that results in a serious injury or fatality was found to be highly stimulating. The physiological data indicate a statistically significant increase in emotional arousal immediately after the accident. This finding reaffirms the importance of using naturalistic injury simulations in generating engagement among workers during safety training programs (Bhandari et al. 2019).

The increase in triggered and maintained situational interest suggests that workers were not only experiencing changes in cognitive and affective processing but also demonstrated an increased and persistent focus with learning material. However, changes in situational interest can be fleeting. Sustaining such knowledge-seeking behaviors is key to translating short-term gains into long-term. This is highlighted by the lack of a statistically significant increase in value-based maintained situational interest, which indicates there is scope to improve not only the design of the training experience but also the content. Furthermore, it also indicates that construction workers are typically in earlier phases of interest and if the interest is sustained, it is possible that multiple learning experiences can lead to dispositional interest. It is worth noting that the modest relationship between situational interest and learning outcomes became apparent only when evaluated across the full sample, suggesting that the effect may be small and more easily obscured by variability or limited power in stratified group analyses. Importantly, maintained value-based situational interest does not require prolonged exposure, but rather depends on learners perceiving the material as personally valuable—something that may take more than a single brief session to develop.

The study did not show any statistically significant relationship between increased emotional arousal and situational interest, and learning outcomes (i.e., hazard recognition, risk perception, risk tolerance, and safety decisions). While most studies have found evidence supporting a positive relationship between engagement in learning environment with academic achievements, the evidence is limited for adult learners in nontraditional/occupational learning environments. Indeed, the same can be said for emotional arousal and behavior; studies have found evidence linking negative emotions with reduced risk-taking behaviors. However, the lack of correlation between engagement and skill improvement here may indicate that the relationship is moderated by context, individual differences, and other relevant factors. It is also possible that the assessment approach used in the study had a confounding effect where the learning experience within the VR environment may not have translated to improved performance in self-report survey with a static image. It could also be that the conditions affecting learning examined in this study may be only peripherally relevant to the content and thereby not correlated with learning achievements. This needs to be examined in future studies.

Limitations

As with any field-based data collection exercise with a quasi-experimental design, this study had several limitations that require recognition. First, the learning experience within the VR was limited to one scene where a pipeline is being welded. This may not be highly relevant for workers in different trades or sectors within the industry. Although the nature of hazards (i.e., energy sources) does not fundamentally change across different trades, and the need for workers to be able to identify hazards in different contexts remains, the lack of familiarity with the work environment must be examined in future studies as it relates to variability in safety performance. Second, the learning experience in the VR environment was self-directed and did not provide explicit instruction. Adults generally prefer to take control of the learning process, and this study provided them with the opportunity to formulate their key take-aways from situated learning exercises. This may not be a universally applicable approach due to differences in prior knowledge levels amongst construction workers. Third, collecting data in the field presented internal validity concerns. While this decision enhanced the ecological validity of the experiment by giving workers training in the environment they are used to receiving training, the authors had limited control over the environment. The authors ensured minimal disruptions by conducting experiments indoors and asking participants to wear noise canceling headphones when they were inside the VR environment. Fourth, it is reasonable to assume that there is inherent discomfort among any participants in reporting their emotional state. The authors sought to minimize this concern by explicitly sharing with participants that their responses were confidential and voluntary. Fifth, although semantic equivalence was established in the survey translation process, subtle differences in emotional tone between English and Spanish wording may have introduced minor variability in responses. This is a known limitation in multilingual field studies where full experimental control is not feasible. Sixth, emotional responses were measured using both self-report surveys and time-stamped physiological sensors to mitigate observer expectancy effects, some degree of response bias may still have been introduced. This reflects a known trade-off in field-based research, where enhancing ecological validity often reduces experimental control. Finally, the multivariate analysis shown in this study presents associative evidence only. Future studies should utilize a different research design to acquire causal evidence.

Future Work

Future research should expand this study in multiple ways. First, it should consider different hazards in various trades or sectors within the industry to ensure the results are consistent across a broader range of work environments. Second, it should incorporate explicit instruction alongside self-directed learning to accommodate workers with varying levels of prior knowledge, ensuring that the training is effective for a wider audience. Third, future work should consider more controlled field conditions to improve internal validity while preserving ecological validity. Fourth, a more robust experimental design, such as a randomized controlled trial, could be employed to provide causal evidence of the effectiveness of VR-based safety training. Lastly, future work may consider other conditions that affect learning beyond emotions and situational interest, such as cognitive load, motivation, etc.

Conclusion

To modernize its safety training methods, the construction industry is increasingly adopting irtual reality to enhance worker safety practices. While early research shows promising results for VR-based training, there is limited investigation into whether VR enhances engagement—specifically, emotions and situational interest—among construction workers, and if this engagement leads to better learning outcomes. This study aimed to address this gap by evaluating the impact of VR-based safety training, alongside traditional methods, on emotions and situational interest, which influence safety practices. Using a quantitative quasi-experimental approach, the study assessed how integrating VR (with and without haptic feedback) into traditional training affects these factors and their effects on learning outcomes. Data were collected from 221 participants across various US construction sectors, including on-site workers and managers.

Parametric tests showed that VR-based training increased negative emotions and decreased positive ones, consistent with previous studies. Findings revealed that VR training effectively elicited emotional arousal and significantly boosted situational interest, especially in VR safety training. However, it did not significantly affect long-term value-based situational interest. Additionally, emotions and situational interest did not influence the learning outcomes from VR experience. These results highlight the potential of VR-based safety training to enhance situational interest and emotional responses, but they also challenge the assumption that emotional engagement and situational interest ensure improved learning outcomes. This research underscores the promise of VR in safety training and emphasizes the need for further exploration of its impact on learning effectiveness.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author upon reasonable request.

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Author Contributions

Jazmin Lopez: Data curation; Formal analysis; Investigation; Writing – original draft. Logan Perry: Conceptualization; Investigation; Methodology; Project administration; Writing – original draft; Writing – review and editing. Siddharth Bhandari: Formal analysis; Investigation; Methodology; Project administration; Supervision. Steven K. Ayer: Funding acquisition; Investigation; Methodology; Project administration; Supervision. Matthew R. Hallowell: Conceptualization; Funding acquisition; Supervision.

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