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Training about Drone Safety Challenges in Construction using a 360 Virtual Environment: Analyzing Learning Effectiveness

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Utilizing drones on construction sites could put workers who are already in dangerous environments into even more risky situations. Therefore, researchers have explored the safety challenges and their countermeasures regarding drone integration into construction sites. This study proposes using a 360-degree virtual reality (360VR) training environment to educate construction professionals on the safety concerns that drones could pose and how to work safely on a drone-populated site. This study specifically focuses on the knowledge gap of how trainees' backgrounds, such as construction experience, work experience with drones, and prior understanding of drones, could be associated with the effects of the training. This study created comprehensive pedagogical intervention content using 360VR, followed by a user-centered pre- and post-experiment. After training, participants' knowledge levels improved by 41% on average. Furthermore, the results indicate that trainees' construction experience and job experience with drones were not associated with their knowledge levels. Moreover, those with lower levels of understanding about drones significantly improved their knowledge scores after the training. The result shows that trainees with different knowledge about drones may be suitable for trainings with different levels of difficulty.

Key Words: Drones, Safety, 360 Virtual Reality (360VR), Immersive Training, Training Assessment

Introduction

The application of drones, or Unmanned Aerial Vehicles (UAVs), has dramatically grown in the construction industry. This includes project planning, progress monitoring, job site inspection, structural health monitoring, and maintenance assessment (Albeaino et al. 2022b). Using drones in construction brings various advantages, such as the capacity to complete tasks more quickly, safely, and inexpensively (Rachmawati and Kim 2022). However, integrating such flying vehicles on site can also bring new types of safety challenges to workers (Brophy et al. 2022). These safety challenges could generally be categorized as physical risks, attentional costs, and psychological impacts (Jeelani and Gheisari 2021). With these additional concerns, the safety issue in the construction industry, which already accounts for 20% of fatal occupational injuries in the United States (U.S. BLS 2019), might worsen. To address this issue, safety training, in particular, to educate construction workers about the challenges when working with or near drones, has been considered critical to prepare workers for these challenges (Mendes et al. 2022). Previous research has developed 360-degree virtual reality (360VR) safety training and demonstrated the effectiveness of the material (Cheng et al. 2022). With the use of VR technology as a medium, the developed training was able to teach workers in a repeatable, safe, and controlled environment while maintaining a sense of presence on a real construction site populated with drones (Albeaino et al. 2022a). However, the effectiveness of the training materials may vary based on trainees' diverse work experiences with drones and their previous understanding of them. As such, there is a need to explore how work experiences and background knowledge associate with the effectiveness of construction worker-drone safety training. To address this knowledge gap, this study will conduct statistical analyses on the association between workers' professional background and their learning effectiveness in the proposed training.

Application of Drones and their Safety Challenges in Construction

Drones are flying vehicles that can be operated remotely without a pilot and be equipped with onboard sensors, such as cameras, LiDARs, and other devices (Mahajan 2021). Recently, construction-associated operations have become one of the top deployments among all drone applications (Kay Wackwitz et al. 2022). This type of robot is increasingly being utilized in construction to perform various tasks, including earthwork surveying, on-site management, progress monitoring, safety inspection, and damage assessment (Rachmawati and Kim 2022). A recent report also pointed out that 54% of construction respondents to its survey believe that drones will become much more common; 21% of respondents stated that drones will be ubiquitous in the construction industry (DroneDeploy 2022). However, a number of studies have demonstrated that the construction industry is still facing barriers and challenges with legal concerns, technical concerns, weather conditions, and safety concerns regarding the decision to drone adoption (Yahya et al. 2021). Among these concerns, the new safety risks that drones may introduce to construction sites could be the most critical since construction is already dealing with unsatisfactory safety performance. In general, these safety challenges could be classified into three categories: physical risks, attentional costs, and psychological impacts (Jeelani and Gheisari 2021). To address these safety concerns, many countermeasures have been discussed in previous research, including regulatory and administrative interventions, technological interventions, training interventions, and cyber and privacy interventions (Jeelani and Gheisari 2021). Notably, the literature has long stressed on the importance of training interventions in moderating the risks associated with drone integration in construction (Albeaino et al. 2022a). Several researchers have begun to make efforts to develop and evaluate training materials educating construction workers about the safety concerns of working around drones on site (Cheng et al. 2022). Nowadays, more construction companies are adopting drones on job sites, which means some workers may have more experience or knowledge about drones than others. Therefore, there is a need for training with different levels of difficulty to educate workers with different backgrounds. However, limited studies have looked to see whether workers' prior knowledge of and work experience with drones are associated with their learning outcomes. This study proposes a 360VR training regarding the safe integration of drones into construction sites and disseminates it to workers to evaluate how their professional backgrounds would relate to learning outcomes.

VR Application for Construction Safety Training

Given the long-lasting poor safety performance in the construction industry, literature has explored more innovative technologies to remedy this issue. One of the recent trends is to apply VR technology to construction safety training to improve the unengaging and insufficient issues of traditional training (Namian et al. 2016). VR is a technology that involves a computer-generated 3D environment to allow users to explore and navigate contents in the environment (Wen and Gheisari 2021). In contrast to the known defects of traditional safety training, VR-based tools have the advantages of being controllable, repeatable, safe, and capable of exposing users to the actual reality of the industry (Albeaino et al. 2022a). More importantly, this method allows users to gain an immersive experience in simulated hazardous scenarios without exposing construction workers to real risk (Jeelani et al. 2020). With the advancement of VR technology, 360VR, which can provide an immersive experience via popular video-sharing sites (e.g., YouTube©), has grown in popularity in the education and training fields (Snelson and Hsu 2020). Although previous research stated that 360VR cannot provide the same level of immersive experience and interactivity compare to head-mounted VR, its advantage of accecibility has made it be considered to present new opportunities for providing more accessible immersive construction safety education (Pham et al. 2018). Also, previous research shows that the effects on knowledge gain, self-efficacy, and engagement are comparable between 360VR and head-mounted VR (Buttussi and Chittaro 2018). Considering such advantages, a pilot study was conducted to examine 360VR effectiveness for training about drones (Cheng et al. 2022). This study builds on the outcome of that research and provides comprehensive training that also includes the countermeasures to the safety concerns of using drones on construction sites.

Research Methodology

The goal of this study is to develop training that educates construction workers about the safety risks that drones may pose, as well as how to work safely on a drone-populated site in a 360VR environment and to investigate the association between workers' professional backgrounds and learning outcomes. The pedagogical and technological design of the training will be presented, followed by a pre- and post-knowledge evaluation of the recruited construction workers. The following sections will discuss about the development of 360VR training and study metric used for the learning effectiveness assessment. These participants were divided into groups based on their professional backgrounds during the analysis phase, and their learning outcomes were compared between groups using statistical methods to investigate their association.

360VR Training Development

Compared to the previous studies (e.g., Cheng et al. 2022), this paper expanded the safety learning objectives of the training to align with the pedagogical goal. In this section, the 360VR training content development will be illustrated from a pedagogical perspective to demonstrate the different parts and delivery strategies of training, followed by the elaboration of 360VR development from a technical perspective.

Pedagogical Design: Training Content and Delivery Strategies

The pedagogical goal of the training is to equip construction workers with the necessary knowledge about the potential applications of drones on sites, the safety challenges they may introduce, and the countermeasures to address the safety concerns. Along with this pedagogical goal, three learning objectives were identified to ensure trainees can (1) define drones and understand their potential applications in the construction industry; (2) identify the potential safety challenges of drone integration on construction jobsites; and (3) propose possible countermeasures regarding the challenges of safely integrating drones on construction sites. The training content was divided into three parts, and the essential topics that should be covered to achieve the learning objective were listed in Table 1. In this phase, the study metric for learning outcome assessment was also developed coresponding to the three learning objectives of proposed training (examples are provided in Table 1).

Table 1

Learning objectives of proposed training, associated contents and assessment questions

Learning Objective	Training Topics	Examples of Assessment Questions
#1: Trainees can define drones and understand their potential applications in the construction industry	Introduction to drones; Drone definition; Drone applications in construction	What industry is the fastest adopter of drones?
#2: Trainees can identify the potential safety challenges of drone integration on construction jobsites	Physical risks; Attentional costs; Psychological impact	List different ways that drones can cause physical harm to workers on roofs.
#3: Trainees can propose possible countermeasures regarding challenges of safe drone integration on sites	Hierarchy of Control; Closure of training	What are the useful suggestions to address the distraction risk posed by drones?

As the training content was established, different pedagogical delivery methods were applied according to specific training elements (Table 2). First, direct instruction, which is often used in teaching basic concepts (Kim 2014), was adopted with a pedagogical agent explaining conceptual topics in front of a display board. Second, the situated learning method, which allows learners to acquire knowledge in realistic settings (Lave and Wenger 1991), was used to instruct potential hazards. The situated learning scenarios were set as tasks involving roofs, scaffolds, and ladders, representing the riskiest working areas on the jobsite (Samantha Brown et al. 2021). Finally, a “bird’s-eye view” from the viewpoint of drones was presented to demonstrate the applications of drones on site. This strategy can motivate students and provide a better understanding of construction site information (Mutis and Antonenko 2022).

Table 2

Pedagogical delivery strategies

Delivery method	Description	Application Scenarios
Direct instruction	A simulation scenario of the site visit. The pedagogical agent stood in front of a display board on the virtual jobsite and explained the conceptual elements.	Introduction of basic conceptual ideas (e.g., drone definition).
Situated learning	The pedagogical agent used the events that happened in the 360-degree scenes on site to explain related training contents.	Training scenarios that could be simulated in the virtual site (e.g., physical risks)
Bird’s-Eye View	A bird’s-eye view of the virtual site was provided, showing different types of drones and their flight paths as well as various construction-related work on the site.	Demonstrate how drones work on the jobsite (e.g., drone applications)

Technical Design: 360VR Development

Throughout this phase, the Unity© game engine was used to construct a 360VR environment with the essential pedagogical elements to execute the delivery strategies. These elements can be categorized as instructional environment, pedagogical agent, and situated scenarios. 360VR components in the virtual environment were constructed corresponding to these elements, including a virtual construction site, a virtual safety-drone trainer, and the training content-related events (Figure 1). Construction equipment, workers, and drones were organized and animated in the virtual environment to create a drone-dominant site. Then, to develop a pedagogical agent with natural verbal and nonverbal languages, a virtual safety-drone trainer was created using text-to-speech, lip-syncing, and animation technologies. Finally, training content-related events were animated according to the project's pedagogical design.

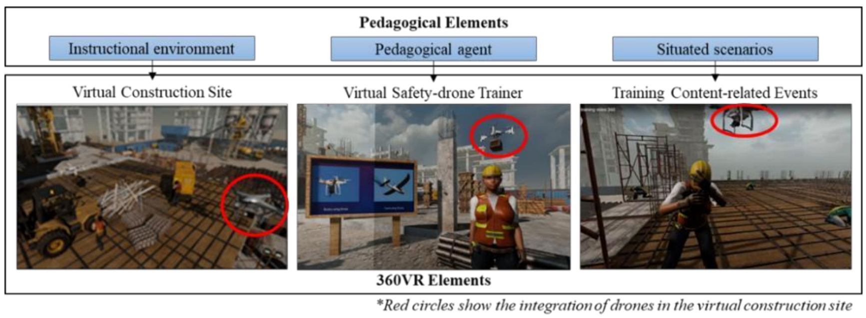

Figure 1 360VR elements correspond to pedagogical elements

Learning effectiveness between different backgrounds

To achieve the research goal of this paper, the survey was aimed at construction workers with varied professional experience and prior knowledge of drones, and the proposed training was delivered via YouTube© to 51 construction workers (39 males and 12 females with average age of 35). The majority of trainees (76%) watched the 360VR training via their laptop or desktop computer. Table 3 provides the demographics of the study participants. In this phase, the participants were divided into different groups according to their professional experience and prior knowledge of drones (Table 3). These group coding was later used for the assessment of result.

Table 3

Group Coding based on construction experience and previous knowledge on drones

Variables	Category	Group Code	Frequency (Percentage)
	<2 years	A0	11 (22%)
Experience in the construction industry	3~4 years	A1	13 (25%)
	Over 4 years	A2	27 (53%)
	Never	B0	11 (22%)
Work experience on projects using drones	1~5 projects	B1	18 (35%)
	6~10 projects or more	B2	22 (43%)
	Low	C0	11 (22%)
Understanding of drones	Medium	C1	22 (43%)
	High	C2	18 (35%)

The participants participated in a pre- and post-knowledge assessment, and the results reveal that after training, participants' knowledge scores significantly improved by 41% on average (from 5.1 to 7.2), indicating the effectiveness of the proposed training material. Furthermore, a one-way ANOVA analysis was performed to evaluate the means of pre- and post-training knowledge scores depending on the diverse professional backgrounds of the participants. As shown in Table 4, there is no significant difference in pre-training knowledge scores between groups with different construction industry experiences; their post-training scores also did not show a significant difference between groups. These results can also be observed when trainees are grouped by their prior work experience with drones. As a result, it is found that prior experience in the construction industry or working on projects involving drones does not result in a different level of knowledge of drone safety in construction either before or after training. In contrast, there is a significant difference in pre-training knowledge scores amongst various groups of people with varying degrees of drone knowledge but no significant difference in post-training knowledge scores. On the other hand, self-reported understanding of drones may actually indicate participants' knowledge level on this topic and therefore cause significant differences in the pre-training scores. However, after training, those groups of participants' knowledge levels can be brought to the same level. Table 5 shows the results of a Tukey HSD (honestly significant difference) test for differences in pre-training means based on the understanding of drones. There are significant differences across all groups of participants, with varying levels of drone understanding.

Table 4

Assessment results based on different professional background

Professional background	Pre-training Mean (SD)			One-way ANOVA		Post-training Mean (SD)			One-way ANOVA	
				F-value	P-value				F-value	P-value
Experience in the construction industry	A0	A1	A2			A0	A1	A2		
	4.9 (2.1)	5.2 (1.3)	5.2 (1.5)	0.182	0.834	6.6 (2.9)	7.7 (1.7)	7.1 (1.5)	0.839	0.438
Work experience on projects using drones	B0	B1	B2			B0	B1	B2		
	5.3 (1.5)	5.1 (1.8)	5.1 (1.5)	0.049	0.952	7.9 (2.1)	6.8 (2.3)	7.0 (1.4)	1.225	0.303
Understanding of drones	C0	C1	C2			C0	C1	C2		
	4.1 (1.1)	5.1 (1.1)	6.7 (1.4)	17.848	<0.01*	6.9 (1.7)	7.1 (2.2)	7.6 (1.8)	0.661	0.521

** P-value < 0.05*

Table 5

Tukey HSD test for differences in pre-training means based on the understanding of drone

Drones understanding levels	Difference of means (SE)	95% CI	P-value
Low vs. High	2.6 (0.4)	(1.55, 3.66)	<0.01*
Low vs. Medium	1.6 (0.4)	(0.55, 2.66)	<0.01*
Medium vs. High	1.0 (0.4)	(0.05, 1.95)	<0.01*

**P-value < 0.05*

The learning outcome assessment results of trainees with different grouping methods are shown in Table 6, and the results of one-way ANOVA are shown in Table 7. The results show that trainees grouped by their construction experience and work experience on projects using drones have increased their knowledge level. However, the increase has no significant differences between groups. Trainees with varying degrees of drone knowledge, in contrast, show differences in learning outcomes, with those with a low and medium level seeing a significant rise in their knowledge scores following training, but those with a high level of understanding did not. Furthermore, the increase in scores among participants with a low level of drone understanding is greater than the increase in scores among those with a medium level of drone understanding, and such an increase brings all trainees up to the same knowledge level as those with a high level of drone understanding. It is found that there is an association between trainees' understanding of drones and their learning outcomes. As such, participants with different knowledge levels of drones may be suited for various training methods. It is suggested that trainees with a higher level of drone understanding could receive a reduced version of the training, while those with a lower level of understanding may benefit more from the training.

Table 6

Learning outcome assessment results of trainees with different grouping methods

Assessment result	Experience in the construction industry			Experience working on projects that used drones			Understanding of drones		
	A0	A1	A2	B0	B1	B2	C0	C1	C2
Pre-training Mean (SD)	4.9 (2.1)	5.2 (1.3)	5.2 (1.5)	5.3 (1.5)	5.1 (1.8)	5.1 (1.5)	4.1 (1.1)	5.1 (1.1)	6.7 (1.4)
Post-training Mean (SD)	6.6 (2.9)	7.7 (1.7)	7.1 (1.5)	7.9 (2.1)	6.8 (2.3)	7.0 (1.4)	6.9 (1.7)	7.1 (2.2)	7.6 (1.8)
P-value	0. 03*	<0.01*	<0.01*	<0.01*	0.02*	<0.01*	<0.01*	<0.01*	0.06

** P-value < 0.05*

Table 7

Learning outcome analysis with trainees' professional backgrounds

Professional background	Learning Outcomes (post-training – pre-training)			One-way ANOVA	
				F-value	P-value
Experience in the construction industry	A0 1.8	A1 2.5	A2 1.9	0.568	0.570
Work experience on projects using drones	B0 2.6	B1 1.7	B2 1.9	1.022	0.367
Understanding of drones	C0 2.8	C1 2.0	C2 0.9	4.668	0.014*

** P-value < 0.05*

Conclusion and Future Work

This study proposes a pedagogical intervention in a 360VR environment to educate construction workers on the safety concerns that drones could pose and how to work safely on a drone-populated site. As an increasing number of construction projects started to adopt drone technology on site, some workers started to have more experience with and knowledge of drone applications in construction. Therefore, there is a need to know if workers with various experiences with or knowledge of drones should receive the same safety training. As such, specific analysis was conducted on whether a worker's construction experience, previous experience working with drones, and knowledge of drones could be associated with their learning effectiveness in training. The proposed pedagogical design of the training includes three different aspects related to the safe integration of drones into construction, namely: the introduction of drones into construction; potential safety challenges of drone integration on construction jobsites; and possible countermeasures regarding these challenges. Following the pedagogical design, three different pedagogical delivery strategies were developed to effectively instruct the knowledge, including direct instruction, situated learning, and bird's-eye view. In the technical development phase, three essential elements in the virtual environment were identified, corresponding to three pedagogical elements to complete the design of the 360VR training. A small sample survey with 51 effective data points was conducted to collect trainees' professional backgrounds and evaluate their learning effects with the developed training content. The ANOVA analysis was conducted to understand the learning effects between different groups of trainees with varying construction experience, prior experience working on projects that used drones, and self-reported understanding of drones. The result indicates that there is no association between participants' construction experiences and their learning outcomes; the same result could be found when trainees are grouped by their previous experience of working with drones. In contrast, significant differences in pre-training knowledge levels were found between trainees with varying understanding of drones, and their knowledge levels were brought to the same level as those who had a high drone understanding level afterward. These findings reveal that workers with varying knowledge of drones may receive different levels of safety training on related topics. For example, workers with higher knowledge of drones could learn how to adopt different countermeasures to address the safety challenges posed by drones on site, while those with insufficient knowledge of drones should receive more comprehensive training. On the managerial perspective, it is suggested that training materials targeting trainees with different levels of prior knowledge could be developed to increase their efficacy. Future research could target the development of different levels of training and collect a larger sample of data to understand further how to develop a more effective training strategy regarding the safe integration of drones into construction. Also, this study did not focus on how different devices would influence trainees' learning outcomes and experiences, future studies could also focus on this topic to gain a better understanding of it.

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