Australasian Journal of Educational Technology, 2026, 42(1).

The effectiveness of virtual reality (VR) for construction skills training

Kate Thompson, Selen Turkay, Ross Brown, Gavin Winter, Alan Burden, Shea Burland, Alex Douglass-Bonner, Cael Gallagher, Jessica Bowler, Allan James, Christopher Lee, Ryan Bargiel, Clint Morrow, Amos Tay
Queensland University of Technology

In order to determine the effectiveness of virtual reality (VR) training and reliability for mass utilisation in competency-based training in the construction industry, we collected data related to learning outcomes (assessment scores and recall, immediately and after 1 month) from 109 participants (*n* = 59, VR group; *n* = 50, non-VR group) from three registered training organisations in south-east Queensland. Interviews were also conducted with 48 of the participants in the VR group. One month after completion of training (VR or non-VR), participants were sent a follow-up survey to assess recall. Our findings showed that the VR environment is as effective as non-VR training for specific learning outcomes immediately as well as after 1 month. Participants identified features that differentiated their learning experience when using the VR environment including the importance of the provision of a safe and secure learning environment as preparation for future learning. This research has implications for the use of advanced technology to support competency-based training in the construction industry as well more broadly.

Implications for practice or policy:

- VR can be used effectively as part of an approach to competency-based training.
- Course leaders should consider the benefits of VR training beyond learning outcomes – in particular in providing a safe and secure learning environment for subject matter that involves physical safety issues in real life.
- Course designers may need to consider how VR could complement traditional training to scale up construction skills training.

Keywords: virtual reality (VR), competence-based training, experimental design, construction skills, safe and secure learning environment

Introduction

Construction education and training serves to enhance the development of construction professionals to meet the needs of a constantly evolving industry. In the construction sector, continuous professional development is necessary for professionals to be engaged in education and training to demonstrate competency in “tacit and explicit knowledge and skills” (Kwofie et al., 2018, p. 639). Virtual reality (VR) has the potential to support experiential learning opportunities that are valuable in contexts that could be unsafe for novices to access otherwise. Reviews and experimental studies suggest that VR is often at least as effective as traditional methods of education, and sometimes more effective, particularly for spatial, procedural and safety-related skills, provided that instructional design manages cognitive load and aligns with clear learning goals (Han et al., 2021; Parong & Mayer, 2021; Renganayagalu et al., 2021). For vocational contexts, recent work has begun to investigate how VR can support knowledge transfer and self-efficacy in vocational education and training (VET) settings, again highlighting the importance of presence, agency and carefully scaffolded tasks (Kablitz, 2025). The purpose of this research was to address the overarching question: "How effective is VR in training for a unit of competency in comparison to traditional methods?" Specifically, the research focused on a unit of competency related to operating elevated work platforms (EWPs), a critical and regulated skill in the construction industry. The study was commissioned by Construction Skills Queensland to provide empirical evidence on the effectiveness of VR-based training relative to conventional, non-VR approaches. The aim was to assess not only learning outcomes but also the learner experience and the feasibility of deploying VR at scale across training organisations.

To address this research question, the broader study examined key dimensions of effective learning in VR: opportunities for learner agency, perceived immersion, recall after 1 month and physical attributes of the training environment – for example, visuals, interactive stations. Design-related aspects were also evaluated, including the reliability of the VR system for large-scale use and the effectiveness of the in-environment feedback mechanisms. This paper focuses on aspects that are critical for the use of VR in tertiary education environments: the effectiveness of VR training and reliability for mass utilisation. In this paper, we will present background information about training in the VET sector as well as educational technology research that has used VR, including the implications of the hardware components in terms of learning and teaching. We will then present the design of the research, data collection and an overview of the participants. The results of the analysis will be presented in relation to the research and design questions, followed by the discussion and conclusion.

Background

Experiential, embodied and situated learning in VET contexts

In this research, we assumed that learning is experiential, embodied and situated. Immersive environments like VR are particularly well positioned to support these forms of learning by creating task scenarios that learners can act in, rather than simply read or hear about. Experiential learning is a well-known theory in education. Kolb (1984, p. 41) described it as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming the experience". This perspective emphasises how cognition, emotion and environmental interaction are integrated over cycles of doing, reflecting, conceptualising and trying again.

Embodied learning is a pedagogical approach that emphasises the role of the body in learning and builds upon the embodied cognition theory, which states that the body is greatly responsible for our experiences of space (Turner, 2016). For working-at-heights training, learners must coordinate perception, movement and tool use in confined spaces and at elevation; their bodies and equipment (e.g., harnesses, elevated work platforms) are not incidental but central to task performance. Situated learning occurs when a learner experiences and applies learning in a specific environment or setting that has its own social, physical and cultural contexts (Dawley & Dede, 2014, p. 1). In VET, learning is not just about recalling procedures but also about being able to act competently in real or realistically simulated workplaces.

Given the type of learners involved in this study – adult workers and trainees in the construction industry – these three perspectives are highly relevant. Their professional learning is typically hands-on, occurs in or near authentic worksites and requires integrating procedural knowledge, safety norms and bodily skills in context. We therefore conceptualised effective training as learning that is experiential (learners actively carry out tasks and see consequences), embodied (they use their bodies and tools in realistic ways) and situated (activities are framed within realistic work scenarios and constraints). This theoretical stance aligns closely with contemporary approaches to competency-based VET.

Competency-based education and VET

The concept of competence has been utilised for decades in VET (Gonczi, 1994; Mulder et al., 2007). Competency-based training has been the foundation of VET in Australia (Misko & Circelli, 2022; Smith, 2010). The competency approach to assessment focuses on improving competency and assessment of learning, rather than identifying incompetence in high-stakes summative assessments (Harris et al., 2017; Schuwirth & Ash, 2013). Competence is thus not only knowing what to do but also being able to perform safely and reliably in context.

It is based on the premise that skills and knowledge should be integrated with practice (Gonczi, 1994). It is a workplace-based form of assessment well suited for vocational education. This approach to assessment encompasses "direct observation and constructive feedback of experts" (Harris et al., 2017, p. 604). The alignment of skills, knowledge and practice is consistent with the view by Hager (2004) that learning is an ongoing process.

Our study sits at the intersection of these perspectives: we treat VR as a way to create embodied, situated experiences that can scaffold the competency-based assessment of working-at-heights skills. The central question is whether such VR-based experiences can support the same (or better) knowledge and procedural recall as conventional training, while aligning with how competence is defined in VET.

VR for learning: The cognitive affective model of immersive learning model and empirical evidence

In the last decade, VR has re-emerged in the consumer marketplace thanks to increased computer-processing power, graphics and display technologies (Osti et al., 2020; Parong & Mayer, 2021). The computer-driven simulations generated in VR create immersive environments where the user can experience unique insights. The immersive experience is limited only by what the user perceives through sensory feedback – predominately visual and auditory, but increasingly using haptics to provide touch capabilities (Li et al., 2018). The hardware that provides these experiences comes in many forms, which include room-sized projector-based systems for multi-user engagement as well as tangible devices for individuals that allow physical interaction with virtual objects (Davila Delgado et al., 2020). The use of head-mounted displays (HMDs) has advanced alongside 3D gaming (Renganayagalu et al., 2021) and has become a viable product for education and training (Vasilevski & Birt, 2020) and provides cost-effectiveness compared to other traditional training methods (Vahdatikhaki et al., 2019). Due to the affordances that VR provides to immersive interaction along with options for spatial head tracking, the use of VR for learning has been investigated in relation to spatial training skills, cognitive awareness and natural interaction and immersion (Han et al., 2021; Renganayagalu et al., 2021). For this reason, studies that include VR often relate to spatial knowledge acquisition skills, such as visual scanning, head movements and observation (Sacks et al., 2013).

From a learning-theoretic perspective, the cognitive affective model of immersive learning (CAMIL; Makransky & Petersen, 2021) offers a useful lens on how VR can support (or hinder) learning. CAMIL proposes that immersive VR has two core psychological affordances – *presence* (the feeling of "being there") and *agency* (the sense of being able to act and influence the environment). These affordances are shaped by technological features such as immersion, control possibilities and representational fidelity and, in turn, influence a set of affective and cognitive processes, including interest, intrinsic motivation, self-efficacy, embodiment, cognitive load and self-regulation (Makransky & Petersen, 2021). These processes ultimately predict factual, conceptual and procedural knowledge and transfer.

CAMIL is compatible with experiential, embodied and situated learning: presence and agency can make learners feel as though they are in a realistic work context, acting with their own bodies and tools, while affective and cognitive factors (e.g., interest, self-efficacy, cognitive load) determine whether those experiences translate into robust learning. Recent empirical work using CAMIL has shown that immersion and interactivity can improve motivation, embodiment and perceived learning, but that high immersion can also increase cognitive load if activities are poorly designed (Parong & Mayer, 2021; Petersen et al., 2022). In our study, we drew on CAMIL to interpret how the design of the VR working-at-heights module – its level of immersion, control and representational fidelity – may have shaped learners' sense of presence, psychological safety and cognitive load, and thereby their learning outcomes.

Construction industry context and VR-based safety training

VR has had applications in numerous fields – from its initial development for military purposes (Vahdatikhaki et al., 2019; Wang & Dunston, 2007), examples from other areas can be seen in disciplines such as psychology (Riva, 2005), engineering and consulting (Söderman, 2005), design (Oh et al., 2004) and marketing (Nantel, 2004). One primary application domain for VR is industrial and construction safety training. Construction is an industry that has begun to utilise and assess VR to enhance the learning experiences, task performance, retention and engagement (Osti et al., 2020). The construction industry represents a labour-intensive sector of the workforce and is a vital component of the global economy. The completion of construction projects is highly dependent on labour productivity levels for enterprises to remain competitive (Manoharan et al., 2023; Nasirzadeh et al., 2022). Developing core competencies such as construction-related knowledge and skills is a vital part of VET towards raising and maintaining labour productivity within the construction industry (Nuwan et al., 2021). The importance of education and training is further reinforced in a review study that revealed skills training to be a major factor influencing construction labour productivity (Nuwan et al., 2021).

Compliance in the construction sector is critical to not only productivity levels but, importantly, the enforcement of safety standards at the construction site (e.g., compliance to personal protective equipment (PPE; Ebekozien, 2022). For decades, it has been widely recognised that low levels of safety compliance could contribute to higher injury and death occurrence (Dingsdag et al., 2006). The lack of safety training was one of the key factors that contribute to non-compliant practice, such as not wearing PPE, at the construction work site (Jalil Al-Bayati et al., 2023). It is therefore imperative for training organisations to develop educational modules that promote greater levels of compliance to safe construction practices.

The construction industry has evolved to increasingly adopt technology as part of its construction education and training (Aliu & Aigbavboa, 2023). Construction training organisations are compelled to design educational modules that develop key competencies among construction professionals (Manoharan et al., 2023). VR has been used in training relevant to the construction industry in various areas, such as safety management (Abotaleb et al., 2023), skill acquisition (Osti et al., 2021), maintenance operation (Palmarini et al., 2018) and equipment operation (Vahdatikhaki et al., 2019). With safety a primary concern at construction sites, improving construction workers' ability to identify potential hazards is a key component of construction training (Sacks et al., 2013). The need to train construction workers' ability to function proficiently in a safe manner is increasingly met with the affordances provided by VR-based modules (Wang et al., 2018). A learning environment utilising VR technology means that construction operators could be immersed in safety training, for example, the identification of hazards in construction sites, without significant safety concerns (Abotaleb et al., 2023). Similarly, personalised guidance during VR training could lead to improved skills related to the inspection of common hazards, including struck-by, fall, caught-in/between and electrical – all of which could potentially lead to fatalities at the construction site (Li et al., 2022).

Despite the benefits afforded by VR in construction training, the effectiveness of VR in learning varies based on training context (Man et al., 2024). Specific contexts in the construction industry that have reported on the use of VR for training include stone-cladding and concrete work (Sacks et al., 2013), work-at-height operations (Habibnezhad et al., 2019; Loreto et al., 2018), as well as the operation of a hydraulic excavator (Otsuki et al., 2023). This heterogeneity in content and VR quality suggests a need for context-specific evaluations of VR systems. Our study responds to this gap by examining the effectiveness of a VR system for working-at-heights training within a competency-based VET framework, focusing on both immediate and 1-month recall and on learners' experiential accounts of the VR training.

Methods

Research design

We adopted a mixed methods, between-groups experimental design with two training conditions: a VR training condition and a non-VR (traditional) training condition. Participants in the VR condition completed the VR-based EWP training module described below, whereas participants in the non-VR condition completed the standard training delivered at the registered training organisation (RTO) (classroom theory using PowerPoint slides and workbook materials, followed by practical operation of an elevated work platform in a warehouse space). Learning outcomes and experiences were compared across these two conditions using quantitative assessment scores and recall measures, alongside qualitative interview data. We implemented a mixed methods approach and collected data from 109 participants (VR group = 59, non-VR group = 50) at three RTOs in south-east Queensland: RTO-A, RTO-B and RTO-C. Quantitative data was collected from questionnaires and assessment protocols for the unit of competency, and qualitative data from interviews. One month after the VR or traditional training, participants were sent a follow up survey to report what they remembered from their experiences with the training as well as to answer the same set of recall questions. In each RTO, the equipment used and the procedures followed were consistent.

The research team obtained ethics approval for this experiment from the Queensland University of Technology Human Research Ethics Advisory Committee – Ref Number 4545.

Through discussion with the project stakeholders, including representatives of the industry organisation, an RTO, educators and VR developers, the following overarching research question was identified: "How effective is VR in training for a unit of competency in comparison to non-VR methods?" In addition to this overarching effectiveness question, we aimed to addressed the following sub-question: "How do learners experience the VR-based working-at-heights training, particularly in relation to realism, psychological safety, pacing and control, interactivity and attention, compared to their prior training experiences?"

VR training system design

The focus of this study was on a unit of competency related to operating EWPs as this was offered at many RTOs, and people who worked in the construction industry (as well as other industries) were required to undertake the training regularly. It consists of both a theory component (a lecture delivered with PowerPoint slides and a workbook for students to complete) and a practice component (in which students are expected to operate an elevated work platform, such as a scissor lift, in a warehouse space).

The VR training system was developed from the training elements obtained from an RTO. The VR application contains several phases presented as a sequence of stations aligned to learning objectives. Participants were sent to different stations within a warehouse, which included tasks such as reviewing documents, identifying hazards and identifying PPE (all of which were connected to identified learning intentions from the RTO's materials and assessment task). They were then instructed to approach the scissor lift, perform appropriate checks, before driving it to the lightbulb, replacing the lightbulb, driving the scissor lift back and packing up appropriately.

Elements that have been established in the VR training system include a high-quality large-scale warehouse model, a detailed highly interactive scissor lift and high-quality animations with interactive items such as PPE (see Figure 1).

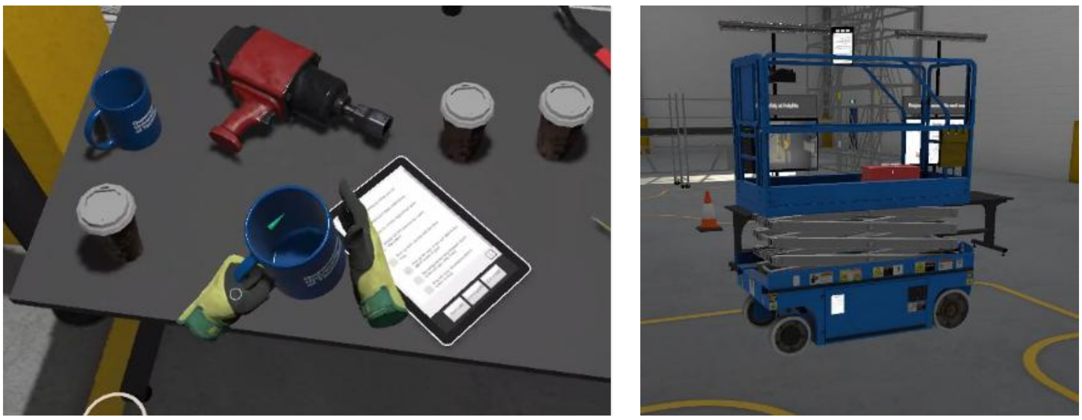

Figure 1. Important visual elements such as animated hand movements (left) and high-quality models (right)

Research has shown that such elements as level of detail (Harman et al., 2019) and realistic hand representations increase a sense of presence in VR (Yoon et al., 2020), improving the cognitive outcomes and levels of engagement in the content (Petersen et al., 2022). The system has been implemented in the Unity game engine, using the Hurricane VR and HexaBody frameworks.

Meta Quest 2 headsets were selected to facilitate easy movement by avoiding restrictive tethers. Running the VR software on the headset itself would introduce quality restrictions that could interfere with experimental results. To support the use of these tether-free headsets for data collection at the RTO, the software ran on powerful gaming laptops, streaming the VR environment via a high-speed wireless device to the headset (see Figure 2 below). Streaming in this manner supported the use of a high-quality VR training system on tether-free headsets. Experiments were conducted with pairs of streaming headsets at the RTOs resulting in more efficient data collection.

Figure 2. User testing at RTO with training staff

Participants

Data were collected at three RTOs in South-East Queensland: RTO-A, RTO-B and RTO-C. In total, 109 adult learners enrolled in working-at-heights or elevated work platform (EWP) training took part in the study. Participants were current workers or trainees in construction and related industries and were completing mandatory EWP competency training as part of their employment or professional development.

The sample was divided into two groups corresponding to the training modality: a VR training condition (experimental group) and a non-VR training condition. Participants in the VR group (n = 59) completed the VR-based EWP training module described above. VR participants were recruited across all three RTOs (see Table 1). At each site, the RTO promoted the study to learners scheduled for training (e.g., announcements by trainers or managers, direct invitations from the research assistants). Interested learners volunteered to complete the VR training session and associated measures on site. Participants in the non-VR group (n = 50) were recruited from RTO-A only to limit any variation in training approaches between RTOs for the non-VR group. For these participants, we collected only their assessment scores. These learners completed the standard RIIWHS204E Work safely at heights training delivered by the RTO, which consisted of approximately 6 hours of combined theory (classroom-based instruction and workbook activities) and practical EWP operation in a warehouse environment. For this group, we obtained consent to access their standard assessment books and invited them to complete the one-month follow-up recall survey.

Table 1
Number of VR group participants at each RTO

RTO	*N* (VR training)	*N* (1 month retention)
RTO-A	28	10
RTO-B	16	12
RTO-C	165	10

Most participants in the VR group identified as male (51) and the rest (8) identified as female. The average age of the 47 participants who chose to share their age was 30.47 (*SD* = 8.94). We asked participants to indicate their highest level of education, and the majority of participants had at least completed high school. Four participants had some high school experience; 28 graduated from high school; 19 graduated from a trade school; six had a bachelor's degree; and one had a master's degree. Most participants reported that English was their primary language. Only six indicated that English was their second language. Participants came from various occupations in the construction industry. These consisted of boilermaker, carpenter, operations technician, electrician, builder, pallet racker, structural engineer, estimator, operational manager and administrator.

We asked participants whether they had previously undertaken working-at-heights training. A total of 53 had undertaken training before. Of those who indicated that they had completed training and reported how many sessions they had participated in, most (17) had participated in one training session and the rest (11) had participated in 2–5 training sessions, one had undertaken more than 6 training sessions.

Data collection

Each data collection session required a desktop computer, an Oculus Quest 2 HMD, and a link cable to connect the HMD to the computer to stream the VR experience. At RTO-A, a backpack computer was connected to a computer monitor. At RTO-B and RTO-C, high-performance laptops were used for data collection.

The data collection procedure differed in the ways that participants were recruited according to the preferences of the RTOs. After recruitment, the procedure was the same at the RTOs. The steps were introduction, pre-survey, VR training simulation, post-survey, post interview and recall. During the introduction, members of the research team introduced themselves to the participant and briefly described what the participant would be expected to do in the data collection session. Participants read the information sheet approved by the university's Ethics Committee and agreed by typing their full name on the consent form to participate in the study. The pre-survey was a short questionnaire about participants' demographics (age, gender, level of education, occupation), prior EWP training experience and their familiarity with VR and video games. The participants then completed the VR training simulation (20 minutes) using the Oculus Quest 2 HMD. The post-survey (10 minutes) included usability, user experience and recall questions. Final open-response recall questions were asked and recorded by the research assistants to ensure that typing skills were not a contributing factor to the final scores. A 5–10 minute post-interview asked participants to detail their experiences with the VR training simulation. The interviews were recorded for transcription and analysis. One month after the data collection on site, participants were emailed a follow up survey to capture their delayed affective experiences and recall.

Measures

Both groups were asked to participate in the pre-survey, which included bespoke items capturing demographics (age, gender, education, occupation), prior working-at-heights or EWP training (e.g., number of previous training sessions) and technology background. Familiarity with VR and familiarity with video games were each assessed with a single item on a 5-point Likert scale (1–5), where higher scores indicated greater familiarity. These items were used descriptively to characterise the sample.

The recall assessment was administered to both groups, immediately and after 1 month. Learning outcomes were assessed using ten recall questions adapted from the collaborating RTO's theory and practical assessment for the working-at-heights or EWP unit. The questions targeted:

- Hazard identification and hazard controls (e.g., "What is a hazard?", "What are three controls of hazards, from most to least effective?")
- Understanding of PPE (e.g., "What is PPE?", "What are the three types of PPE?")
- Fall prevention devices and harness inspection
- Correct placement of tools and equipment in the EWP basket
- Key steps in safe EWP operation (e.g., "What 4 things should you do when operating the EWP?", "What should you do before you lower the platform?").

Responses to these items were scored against an answer key provided by the RTO, with items coded as correct or incorrect (0–1) or on a small integer scale (e.g., 0–3) depending on the number of required elements. The same set of ten questions was administered immediately after training and again 1 month later in the follow-up survey for both VR and non-VR participants.

In addition, participants answered an open-response question: "Please describe the steps in as much detail as you can that you go through to carry out work at heights safely. Example work: change a lamp at a large warehouse." These responses were coded using the RTO's assessment checklist for safe EWP operation, which specifies seven key steps:

1. Selecting and inspecting tools and safety equipment
2. Performing platform checks on the EWP (pre-start and operational checks, fault reporting)
3. Setting up the EWP for operations (ground assessment, stabilisation, isolating the work area, securing tools)
4. Operating the EWP (responding to alarms, managing hazards, following the work plan)
5. Parking and shutting down the EWP
6. Conducting post-operational checks and responding to faults
7. Completing housekeeping (clearing the work area, checking and storing equipment).

For each step, coders recorded whether it was mentioned (1) or not mentioned (0), producing seven binary indicators per participant. The same coding scheme was applied to immediate and 1-month responses.

Following the post-survey, participants in the VR condition completed a short semi-structured interview (approximately 4–10 minutes) to explore their experiences with the VR training. The interview guide comprised two main sections: feedback on performance and perceptions of the VR training environment. The feedback on performance questions asked participants to describe the feedback they received from the research assistant and within the VR training environment and (where applicable) to compare this to feedback received in previous physical working-at-heights training or on a real job site. The perceptions of the VR training environment questions focused on what participants did in the VR scenario, what they liked best, what they found worse or more challenging than physical training and what they would change if they were in charge of the VR training. The interview concluded with an open invitation for any additional comments.

These interviews were used to investigate themes such as comparisons between VR and physical training, perceived realism and physicality, stress and psychological safety, pacing and control and interactivity and engagement with the VR environment.

Data analysis

This study was designed using a convergent mixed methods approach (Creswell & Plano Clark, 2007). Survey data was analysed using descriptive (e.g., means and standard deviations) and inferential statistics

(Independent samples *t* test to examine the differences between groups on outcome variables). For all independent-samples *t* tests, we report the test statistic with degrees of freedom and *p* value and we include effect sizes as Cohen's *d* (based on the pooled standard deviation), with negative values indicating higher scores in the non-VR group.

Interviews and open-response items were analysed using thematic analysis, following the six-phase approach outlined by Braun and Clarke (2006): familiarisation with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes and producing the report. We used a combination of deductive (theory-informed) and inductive (data-driven) coding.

Before coding, the research team developed a small set of theory-informed *sensitising* codes were developed based on prior work on simulation-based learning, VR training, and competency-based education. These deductive codes included comparisons to physical training (comments explicitly comparing VR to previous face-to-face or on-site training); physicality and realism (perceptions of bodily sensations, equipment feel and environmental realism); feedback and guidance (how instructions, corrections and prompts were received from the VR system or trainer); stress, risk and psychological safety (references to feeling safe or unsafe, anxious, under pressure or free to make mistakes); pacing, personalisation and control (perceived control over the pace, order, and timing of activities); interactivity and *learning by doing* (emphasis on hands-on action versus passive listening or reading); and attention and distractions (comments about focus, distraction or competing demands during training).

Two of us independently coded an initial subset of transcripts using these deductive codes while remaining open to new meanings in the data. During this process, several inductive codes were added to capture recurring ideas that were not fully covered by the initial framework. Examples of these inductive codes included fear of damaging equipment; relief at not being watched by peers; linear or "baby steps" structure of VR; VR as game-like, mental effort versus physical effort; and repeating steps to build confidence. These codes were defined iteratively through team discussion, with brief written descriptions attached to each code in NVivo to ensure consistent application.

After coding all transcripts, related deductive and inductive codes were clustered into higher-order themes. The final themes reported in the Results section – Comparisons to physical training; Physicality and realism, Stress, risk and psychological safety; Pacing, personalisation and control; Interactivity and engagement through doing; and Increased attention and reduced distractions – each comprised a combination of theory-informed codes (e.g., comparisons, realism, stress, pacing) and refined inductive codes that captured participants' specific experiences (e.g., fear of damaging equipment, feeling safer without being observed, seeing VR as more game-like and engaging). Disagreements about coding or theme boundaries were resolved through discussion until consensus was reached.

Results

Most participants were not familiar (M = 2.2, SD = 1.08). Only four people reported being very familiar or extremely familiar with VR. The latter group owned their own HMD. A total of 35 participants reported being not at all or slightly familiar with VR. The remaining 20 stated that they were moderately familiar with VR. Participants were moderately familiar with video games (M = 3.24; SD = 1.09). A total of 28 participants reported they did not play video games weekly. A total of 17 said they played 1–3 hours a week, and eight participants reported playing 4–6 hours a week. Only five played 7 or more hours a week.

Immediate assessment of learning

Participants' learning was assessed using a set of recall questions outlined earlier both immediately after the VR-training, and 1 month after the training. For the non-VR group, we obtained students' assessment books from the collaborating RTO for immediate learning assessment, and they were sent a survey 1 month after their training. These responses to the assessment questions were scored by a research assistant using an answer key provided by the RTO.

The topics included in the assessment are shown in Table 2, with one or two questions in the assessment associated with each of these topics. The results of the comparison between VR and non-VR groups for individual questions are reported in Table 2.

Table 2
Theory elements, immediate assessment – group descriptive statistics

Question	Group	*N*	*Mean*	*SD*	*SEM*
		Hazards and the elimination of hazards			
Q1	VR	47	.92	.28	.04
	non-VR	50	.96	.20	.03
Q2	VR	39	1.88	1.38	.22
	non-VR	41	2.20	1.35	.21
		PPE			
Q3	VR	42	.88	.33	.05
	non-VR	47	.96	.20	.04
Q4[a]	VR	43	2.95	.21	.03
	non-VR	23	3.00	.00	.00
		Fall prevention devices and harness inspection			
Q5	VR	42	2.31	.92	.14
	non-VR	43	2.98	.15	.02
Q6[b]	VR	43	1.37	.49	.08
	non-VR	24	1.25	.44	.09
		Location of tools and equipment			
Q7[c]	VR	41	.96	.13	.02
	non-VR	23	1.00	.00	.00
		Operating the EWP			
Q8[d]	VR	39	3.09	.83	.14
	non-VR	22	4.00	.00	.00
Q9[e]	VR	42	.88	.29	.05
	non-VR	22	1.00	.00	.00

[a,b,c,d,e]Q4, Q6, Q7, Q8 and Q9 were removed from the RTO-A assessment; thus, we do not have responses to these questions from all participants.

Hazards and the elimination of hazards. No significant differences were found between the groups in relation to how well they answered the two questions about hazards and the elimination of hazards. For Q1, most answered correctly (see Table 2), and there was no significant difference between the groups ($t(95) = -.92$, $p = .36$, $d = -0.17$). This was similar for Q2, which was scored out of 3. There was no significant differences between the groups on how they answered this question ($t(78) = -1.06$, $p = -.29$, $d = -0.23$).

PPE and *Fall prevention devices and harness inspection*. We found no significant difference between the groups on how they answered the questions related to PPEs. Most participants in each group could define the role of PPEs ($t(87) = -1.3$, $p = .197$, $d = -0.30$), and could list three types of PPEs ($t(64) = -1.04$, $p = .301$, $d = -0.29$).

There were also no significant differences between groups with respect to how to inspect the harness ($t(83) = 1.01$, $p = .31$, $d = -1.02$). Participants in the non-VR group could identify significantly more fall prevention devices compared to the VR group ($t(65) = -4.62$, $p < .001$, $d = 0.25$). However, this might be expected as there was no explicit teaching of this knowledge in the VR training simulation.

Location of tools and equipment. Both groups identified tools and equipment needed for the EWP operation equally well ($t(41) = -1.78$, $p = 0.83$, $d = -0.38$).

Operating the EWP. There were significant differences between the groups in relation to EWP operation. The Non-VR group listed significantly more steps than the VR group did ($t(39) = -6.82$, $p < .001$, $d = -1.37$), and gave a correct answer to what they should do before lowering the EWP ($t(42) = -2, 68$, $p = .011$, $d = -0.51$).

Carry out work at heights safely. In an open-response question (i.e., "Please describe the steps in as much detail as you can that you go through to carry out work at heights safely. Example work: Change a lamp at a large warehouse."), the participants were asked to describe the steps necessary to carry out work at heights safely. The steps were select tools and equipment based on task requirements; platform checks; set up the elevated work platform for operations; operate the elevated work platform; park and shut down the elevated work platform; carry out post-operational checks and respond to any faults identified; and complete housekeeping procedures after operations. These were evaluated based on the assessment checklists to operate the elevated work platform. We coded whether participant in the VR group correctly identified the step or not. Please see the descriptive statistics for each step below (Table 3).

Table 3
Seven steps in EWP operation, immediate assessment – group descriptive statistics

	Step 1	Step 2	Step 3	Step 4.	Step 5	Step 6	Step 7
M	.92	.92	.87	.77	.37	.15	.14
N	39	39	39	39	39	39	37
SD	.27	.27	.34	.43	.48	.37	.35

Most people described the initial steps of operating the EWP well (Steps 1–4) but omitted the later steps (5–7).

Assessment of learning – 1-month retention

The same questions were asked 1 month after the participants completed the training, and the comparison between the assessment results for the VR and non-VR group are reported in Table 4.

Table 4
Theory elements, 1-month retention – group descriptive statistics

Question	Group	*N*	*Mean*	*SD*	*SEM*
		Hazards and the elimination of hazards			
Q1	VR	28	.88	.30	.06
	non-VR	15	.93	.26	.07
Q2	VR	27	2.52	.89	.17
	non-VR	13	2.08	1.19	.33
		PPE			
Q3	VR	28	.80	.39	.07
	non-VR	15	1.00	.00	.00
Q4	VR	28	2.89	.57	.11
	non-VR	15	2.80	.78	.20
		Fall prevention devices and harness inspection			
Q5	VR	27	2.67	.73	.14
	non-VR	15	3.00	.00	.00
Q6	VR	27	1.67	.48	.09
	non-VR	15	1.60	.51	.13
		Location of tools and equipment			
Q7	VR	27	.83	.31	.06
	non-VR	15	.93	.26	.07
		Operating the EWP			
Q8	VR	25	2.76	.98	.20
	non-VR	14	2.64	.75	.20
Q9	VR	27	.80	.29	.06
	non-VR	14	.71	.38	.10

Hazards and the elimination of hazards. We found no significant differences between the VR and non-VR groups for the items related to hazards and the elimination of hazards (Table 4). Both groups were able to provide similar answers to the two questions about hazard identification (t = -.65, p = .52) and hazard elimination (t = 1.31, p = .20).

PPE and *Fall prevention and harness inspection*. There were significant differences between the VR and non-VR group in relation to PPE. More participants from the non-VR group gave a complete definition of PPE (t = -2.65, p = .013) but both groups gave similar responses to the example PPEs (t = .45, p = .66). There were no significant differences between the groups on the way in which they answered the questions about fall prevention devices and harness inspection (Q5, t = -2.36, p = .026; and Q6, t = 423, p = .675).

Location of tools and equipment. Similar to the immediate test, we found no significant difference between the VR and non-VR group in relation to how they answered the question about tools and equipment (t = -1.06, p = .296). Both the VR group and the non-VR group were able to answer this question.

Operating the EWP. In contrast to the results from the assessment conducted immediately after training, we found no differences in how groups answered these two questions related to operating the elevated work platform. The VR and non-VR groups gave similar number of correct steps to Q8 (t = .39, p = .70) and Q9 (t = .78, p = .44).

Carry out work-at-heights safely. We compared VR and non-VR participants' responses to their description of how to carry out work at heights for each seven steps (Table 5).

Table 5
Seven steps in EWP operation1-month retention – group descriptive statistics

Step	Group	*N*	*Mean*	*SD*	*SEM*
Step 1	VR	23	.78	.42	.09
	non-VR	13	1.00	.00	.00
Step 2	VR	23	.87	.34	.07
	non-VR	13	.77	.44	.12
Step 3	VR	23	.70	.47	.10
	non-VR	13	.85	.38	.10
Step 4	VR	23	.91	.29	.06
	non-VR	13	.85	.38	.10
Step 5	VR	23	.61	.50	.10
	non-VR	13	.46	.52	.14
Step 6	VR	23	.30	.47	.10
	non-VR	13	.39	.51	.14
Step 7	VR	23	.26	.45	.09
	non-VR	13	.08	.28	.08

Overall, there was no significant difference between the groups: Step 1 (t = -2.47, p = .022), Step 2 (t = .76. p = .452), Step 3 (t = -.987, p = .330), Step 4 (t = -60, p = .553), Step 5 (t = .84, p = .408), Step 6 (t = -.48, p = .635) and Step 7 (t = 1.34, p = .138).

Interviews

Following the VR training experience, participants were invited to reflect on how it compared to their prior training and what aspects they found beneficial, challenging or worth changing. A total of 48 participants shared their VR experiences in the interviews lasting between 4 and 10 minutes. Their reflections revealed diverse yet converging insights into the effectiveness and limitations of VR-based learning. A subset of the responses to the questions are reported on here. Specifically, participants were asked to talk about VR training they completed and what they liked about it, what they found challenging and what they would change.

Comparisons to physical training

Participants' evaluations often began with direct comparisons between the VR training and traditional, in-person training. While some described the VR experience as a fairly accurate representation, others noted critical differences. Several participants acknowledged similarities in task types, such as hazard identification and EWP operation. For example, one participant highlighted that, "aside from the swaying" (P154), driving the EWP sufficiently matched their real-life experience. Some indicated that they did more driving and had more interactions with the EWP in the VR training than was provided in their physical training:

> It's pretty close to what we ... when we did ours on the scissor lift and that, it was quite small and that, but ... And the same sort of thing, you know, you had to go up and, you know, do your task and things like that. But yeah, no it was pretty, pretty close to what I thought, yeah. (P144)

Other participants stated that VR lacked the fluidity of real-world training. P117, for example, stressed a stark contrast: "There's not really so much oversight … the robot lady basically talks to you as if you don't know anything". Several described VR as being more linear in structure, unlike the often unstructured and self-directed experiences they encountered on-site – for example, "[In the VR training] now you need to put this thing and do that thing, and do that. Whereas out on site or it'll be ... I don't know, it just won't be as structured" (P128).

Physicality and realism

Participants raised concerns about the lack of physical feedback in the virtual environment. This was one of the most consistent criticisms across interviews. P117 insisted that there were absolutely no similarities between the two types of training:

> No, there's not really so much oversight. Everyone seems to sort of just be expected to know what to do … And you just carry out your work ... [In VR] very baby steps. Yeah. Just you know, simple steps to follow. (P117)

P117's comments related to the practicality of the VR training mainly came from physically doing the tasks: "Tt does seem more practical because you're actually physically holding something". Practical and physical aspects (especially swaying of the EWP) were, overall, non-comparable between the two types of training for the participants. They gave examples such as the jerky movements of the EWP and motion from moving and stopping that can cause them to fall over in real life:

> That's the only thing you sort of get used to. You're so used to that sort of feedback from the outside world. And then there's no real feedback when you're doing you are actually bracing to move and things will take off and all sudden, everything's moving but you are not moving. That's probably the biggest thing. (P108)

Stress, risk and psychological safety

Many participants viewed the VR training system as a psychologically safer space for learning. This was particularly valuable for novices or those with anxiety about operating large equipment. Several participants compared the intensity of the two training approaches. P124 said the VR training requires more mental work to process all the information than the in-person training which requires more physical interactions and less thinking. Many concluded that VR training was easier and less stressful than in person training as "there is no fear of actually falling down" (P149). On the topic of stress, P136 recalled their in-person training being very stressful and how they were worried about damaging the equipment and making a mess while their trainer was watching them complete the task: "You just feel a bit more safer in the virtual reality" (P136). P153 exclaimed, "I wasn't getting yelled at by the instructor on the VR"

(P153). He further explained that he could not drive the scissor life at his first training in front of the class, and it was “very nerve racking in real life” (P153).

> It was less stressful than the real world. Cause you know you're gonna tip it over and break it. When I did my forklift licence, you had to do the same thing and get stuff off and you're stressing because if it falls, it actually falls. But when you're in there, you know it's not going to hurt anyone …That's probably a good thing … There was no risk of hurting someone. Or ... Driving into a shelf, and then you ripping the shelf out of the floor. And ... I can just drive through it in there. There's no damage, no cost, nothing like that. (P147)

Participants particularly liked how the design of the VR allowed them a safe exploration of different scenarios in a controlled environment without a risk of falling off, damaging equipment or other people. They found it as a good training exercise (n = 13). Many participants saw value of training in the VR environment before trying things on in the real life, especially for novice construction workers:

> If it was someone that had never done any of that stuff before, I think that would be a really good use of learning. Before you actually go out and hop on a two ton machine and possibly hurt yourself, like I think, I think that's great. (P105)

A few others stated that they found it less stressful as they went through the training without a classroom full of people who would observe them.

Pacing, personalisation and control

One of the most celebrated features of the VR training was the ability for learners to proceed at their own pace. This contrasted with classroom settings, where instruction can be rushed or dominated by group dynamics. Participants (n = 17) commented on how they proceeded in the VR training at their own pace and from their own perspective, and with more control about what they do in the virtual environment. It was more of an individual experience for them and it made them feel more in control of the experience. P110 talked about this in the context of feedback:

> Actually, the feedback is, in my opinion, a little better. Because of that, I suppose it would be at my own pace. If in VR training, there was an ability to like sort of pause it and sort of comprehend what she said. As opposed to here, there's like, with a classroom structure, you kind of have to go as quickly as everybody else. (P110)

In the same vein P113 remarked that he liked how the instruction was delivered in the VR environment, “how you're not waiting around for someone else to be taught something before you get taught. It's just at your own pace”, In a similar vein P150 thought the VR training was better than trying to understand what someone else was doing, “because you can just experience it yourself”. (150)

Interactivity and engagement through doing

Interactivity emerged as a central factor in participant enjoyment and engagement. Many described VR as more immersive and hands-on than traditional training. P114 likened it to playing a game: “Operate it like a game in a way and move around … just the interacting of it”. P104 recalled his in-class training experience:

> I've seen the interactive point of view, as in actually being within a simulated working area to then notifying hazards that are directly in front of you, even though it is virtual reality, but you see it there for yourself. So it's a bit different than looking up at a screen and watching a TV show or reading some paper. (P104)

Similarly, P134 stated he was someone who likes to learn by doing things rather than simply reading and watching passively:

> Better than sitting in a classroom, learning it as I did last time, because it was just someone standing at the front, giving you, telling you, whereas this, you're actually doing it, like, 'Ah yep, we need this', and picking things up and looking at them and whatever. So yeah, I feel it was good in that way. (P134)

Increased attention and reduced distractions

With heightened engagement came increased focus. Several participants noted they paid more attention during the VR training than in previous face-to-face sessions. P144 brought up that doing the same training multiple times can cause them to pay less attention to the training:

> It just made me feel like a wee bit more aware of what was around … Because I was paying a lot more attention than what I'd do if I was doing it because I think sometimes you get so blasé if you're in the real world because you've done it so often. (P144)

Others highlighted that classroom distractions or peer interruptions could derail attention – something less likely to happen in VR's individual environment.

Discussion

This study set out to evaluate the effectiveness of VR as a tool for delivering a unit of competency related to EWP training, as compared to traditional methods. Results from immediate and 1-month-delayed assessments revealed no significant differences between the VR and non-VR groups for most learning outcomes, indicating that VR is a viable alternative for theory-based and procedural competency development in the construction sector. This aligns with findings from Gao et al. (2019) and Renganayagalu et al. (2021), which demonstrated that VR can yield equivalent or better results in knowledge retention and skill acquisition compared to conventional methods.

A major theme emerging from participant interviews was the role of psychological safety and reduced stress in the VR learning environment. Learners appreciated being able to make mistakes without fear of equipment damage, embarrassment or injury – factors commonly reported in traditional face-to-face sessions. These benefits resonate with literature in simulation-based education, which has identified risk-free practice environments as a driver for confidence and improved learning (Dhalmahapatra et al., 2021). The lack of social evaluation – often present in traditional classrooms – appears to ease learners into unfamiliar tasks, allowing them to build competence before transitioning to real-world application.

Participants frequently emphasised how VR supported personalised learning experiences, where they could proceed at their own pace, repeat steps as needed and control the flow of instruction. This reflects established benefits of immersive environments, which support learner agency and engagement through autonomy and self-directed navigation (Makransky & Petersen, 2021; Ryan et al., 2006). This level of instructional scaffolding in VR mirrors pedagogical best practices in competency-based education, where learners gradually build mastery (Kolb, 1984).

Another noteworthy finding is the heightened attention and reduced distraction reported in VR environments. Participants noted fewer interruptions compared to traditional classrooms a condition that enhanced their focus. Research supports this observation: immersive VR is known to promote a state of cognitive flow and minimize extraneous distractions, enabling deeper cognitive processing (Han et al., 2021; Parong & Mayer, 2021). This is particularly relevant for high-stakes environments like construction, where attention to safety-critical details can have life-saving implications.

The pedagogical design of the virtual learning environment was viewed by participants as key to the effectiveness of the approach to learning, which supports the findings of other studies (e.g., Kablitz et al., 2025). Informed by the CAMIL model (Makranksy & Peterson, 2021), the experiences in the virtual learning environment were scaffolded and connected, such that each task built on the one before it. In the classroom training environment, learners are able to repeat processes until they have demonstrated the required standard of competency in the particular skill, integrating knowledge and skills with practice (Gonczi, 1994). The design of the VR training system provided opportunities to demonstrate skills (such as the identification of hazards) and included multiple options for selection. The VR training system did not include time pressures or any restrictions on how long participants needed to spend on any of the stages. In the interviews, learners mentioned the positive impact of the lack of pressure in terms of time as well as the agency involved in ensuring they felt prepared before demonstrating a particular skill.

However, the study also highlighted important limitations in the sensory realism of the VR experience. Participants noted the lack of tactile feedback, bodily motion and physical sway – elements critical to operating real EWPs. This limitation has been well-documented in VR literature, where the absence of haptic and vestibular cues can limit transferability to real-world tasks (Vahdatikhaki et al. 2019). This suggests a need for integrating multimodal sensory feedback in future VR system designs to better simulate embodied experiences.

Interestingly, although the VR training system performed well overall, the findings also suggest that content coverage and alignment with assessment goals need continued attention. For example, participants in the non-VR group scored higher on certain operational procedures, potentially due to differences in emphasis or instruction style. These results underscore the importance of aligning VR design with assessment criteria and competency standards.

Limitations and future research

This study has multiple limitations. Although the training content and procedure were standardised across sites, slight variations in equipment setup, technical support and learning environment conditions may have influenced participant experiences. Additionally, most of the non-VR group data were collected from a single RTO, which may limit the generalisability of comparisons across training settings.

The qualitative data were based on short post-training interviews (4–10 minutes) and self-report measures of learning and engagement. While the interviews yielded rich themes, longer or longitudinal interviews could have uncovered deeper reflections on their experiences. Moreover, participants may have provided socially desirable responses, particularly given the novelty of the VR experience. To reduce socially desirable responding, the interviews were conducted by those of us who were not involved in participants' assessment, and participants were explicitly reminded that their responses would be confidential, would not be shared with trainers or employers and would not affect their competency outcomes. The interview guide also included open-ended questions that invited critical feedback (e.g., "What was worse about the VR training environment?" and "What would you change?"). Even with these precautions, the novelty of VR and the research setting may still have encouraged overly positive evaluations.

This study measured immediate and 1-month recall of training content but did not include direct observation of on-site behaviour or long-term retention of practical skills. Thus, while the VR training was effective in supporting knowledge and procedural recall, further research is needed to understand its impact on job performance and skill transfer in real-world construction context (Gao et al., 2019).

Future research could address these limitations in several ways. First, multi-site studies that include non-VR comparison groups from multiple RTOs would help to test the robustness of our findings across different teaching styles and organisational cultures. Second, experimental work that systematically varies features of the VR design (e.g., level of physical realism, type and timing of feedback, degree of pacing control) could clarify which design elements most strongly influence learning, psychological safety and engagement. Third, studies that combine VR training with enhanced haptic or motion feedback and then compare outcomes with purely visual–auditory VR, would help determine how much additional sensory fidelity is necessary for high-risk competencies such as working at heights. Finally, longitudinal and mixed-methods designs that integrate interviews with workplace observations, supervisor ratings and safety records would provide a more complete picture of how VR-based training contributes to long-term competence and safe practice in the construction industry.

Conclusions

This research provides compelling evidence that well-designed VR environments can effectively support competency-based training in the construction industry, performing comparably to traditional training in terms of immediate and delayed learning outcomes. Beyond cognitive gains, VR was particularly effective in fostering a psychologically safe and learner-centred training experience – attributes critical to supporting novice learners in high-risk domains.

While the current VR system lacked some physical realism in terms of physical sensations, it succeeded in areas where traditional training often falls short, such as promoting learner agency, reducing performance anxiety and enabling controlled, repeatable practice scenarios. The findings support other studies (e.g., Dubovi, 2022; Syiem & Türkay 2025) that found that immersive technologies can support deeper cognitive engagement by minimising external distractions and allowing learners to concentrate fully on tasks and allowing learnings to feel more in control and engaged with the material. These strengths point to VR's value as a preparatory tool within a blended learning model, particularly when physical access to equipment is limited or risky.

Going forward, hybrid approaches that combine the cognitive and emotional benefits of VR with the embodied realism of physical practice may offer the most promising pathway for construction training at scale. Future research should explore how VR training influences long-term on-site performance, how to optimise content alignment with assessment frameworks and how to best implement such technologies across diverse training organisations.

Author contributions

Kate Thompson: Conceptualisation, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review and editing; **Selen Turkay:** Conceptualisation, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review and editing; **Ross Brown:** Conceptualisation, Funding acquisition, Project administration, Writing – original draft; Writing – review and editing; **Gavin Winter:** Conceptualisation, Funding acquisition, Project administration, Resources, Supervision; **Alan Burden:** Conceptualisation, Methodology, Software, Writing – original draft, Writing – review and editing; **Shea Burland:** Investigation; **Alex Douglass-Bonner:** Investigation, Writing – original draft, Writing – review and editing; **Cael Gallaher**: Investigation, Writing – review and editing; **Jessica Bowler:** Data curation, Formal analysis; **Allan James:** Methodology, Resources, Software, Validation, Visualisation, Writing – original draft, Writing – review and editing; **Christopher Lee:** Investigation; **Ryan Bargiel:** Visualisation; **Clint Morrow:** Resources, Validation; **Amos Tay:** Writing – original draft, Writing – review and editing.

Acknowledgements

The authors acknowledge the support of Construction Skills Queensland in the funding of this research as well as the RTOs that facilitated the collection of data in this study.

References

Abotaleb, I., Hosny, O., Nassar, K., Bader, S., Elrifaee, M., Ibrahim, S., El Hakim, Y., & Sherif, M. (2023). An interactive virtual reality model for enhancing safety training in construction education. *Computer Applications in Engineering Education*, *31*(2), 324–345. https://doi.org/10.1002/cae.22585

Aliu, J., & Aigbavboa, C. (2023). Reviewing the trends of construction education research in the last decade: A bibliometric analysis. *International Journal of Construction Management*, *23*(9), 1571–1580. https://doi.org/10.1080/15623599.2021.1985777

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. SAGE Publications.

Davila Delgado, J. M., Oyedele, L., Beach, T., & Demian, P. (2020). Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *Journal of Construction Engineering and Management*, *146*(7), Article 04020079. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001844

Dawley, L., & Dede, C. (2014). Situated learning in virtual worlds and immersive simulations. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (pp. 723–734). Springer. https://doi.org/10.1007/978-1-4614-3185-5_58

Dhalmahapatra, K., Maiti, J., & Krishna, O. B. (2021). Assessment of virtual reality based safety training simulator for electric overhead crane operations. *Safety Science*, *139*, Article 105241. https://doi.org/10.1016/j.ssci.2021.105241

Dingsdag, D., Biggs, H., & Sheahan, V. (2006). Changing safety behaviour in the construction industry, using enforcement and education as the stick and carrot to improve safety culture. In L. Adams & K. Guest (Eds.), *Clients driving innovation: Moving ideas into practice* (pp. 214–219). Cooperative Research Centre for Construction Innovation for Icon.Net Pty Ltd.

Dubovi, I. (2022). Cognitive and emotional engagement while learning with VR: The perspective of multimodal methods. *Computers & Education, 183*, Article 104495. https://doi.org/10.1016/j.compedu.2022.104495

Ebekozien, A. (2022). Construction companies' compliance to personal protective equipment on junior staff in Nigeria: Issues and solutions. *International Journal of Building Pathology and Adaptation*, *40*(4), 481–498. https://doi.org/10.1108/IJBPA-08-2020-0067

Gao, Y., Gonzalez, V. A., & Yiu, T. W. (2019). The effectiveness of traditional tools and computer-aided technologies for health and safety training in the construction sector: A systematic review. *Computers & Education*, *138*, 101–115. https://doi.org/10.1016/j.compedu.2019.05.003

Gonczi, A. (1994). Competency based assessment in the professions in Australia. *Assessment in Education: Principles, Policy & Practice*, *1*(1), 27–44. https://doi.org/10.1080/0969594940010103

Habibnezhad, M., Shayesteh, S., Jebelli, H., Puckett, J., & Stentz, T. (2021). Comparison of ironworker's fall risk assessment systems using an immersive biofeedback simulator. *Automation in Construction*, *122*, Article 103471. https://doi.org/10.1016/j.autcon.2020.103471

Hager, P. (2004). The competence affair, or why vocational education and training urgently needs a new understanding of learning. *Journal of Vocational Education & Training*, *56*(3), 409–433. https://doi.org/10.1080/13636820400200262

Han, Y., Diao, Y., Yin, Z., Jin, R., Kangwa, J., & Ebohon, O. J. (2021). Immersive technology-driven investigations on influence factors of cognitive load incurred in construction site hazard recognition, analysis and decision making. *Advanced Engineering Informatics*, *48*, Article 101298. https://doi.org/10.1016/j.aei.2021.101298

Harman, J., Brown, R., Johnson, D., & Turkay, S. (2019). The role of visual detail during situated memory recall within a virtual reality environment. In A. Lugmayr, M. Masek, M. Reynolds, M. Brereton, R. Kelly, V. Roto, I. Richardson, H. Shen, C. Parker, N. Ahmadpour, J. Li Tay, J. Donovan, & Si. Perrault (Eds.), *Proceedings of the 31st Australian Conference on Human-Computer-Interaction* (pp. 138–148). Association for Computing Machinery. https://doi.org/10.1145/3369457.336946

Harris, P., Bhanji, F., Topps, M., Ross, S., Lieberman, S., Frank, J. R., Snell, L., & Sherbino, J. (2017). Evolving concepts of assessment in a competency-based world. *Medical Teacher*, *39*(6), 603–608. https://doi.org/10.1080/0142159X.2017.1315071

Jalil Al-Bayati, A., Rener, A. T., Listello, M. P., & Mohamed, M. (2023). PPE non-compliance among construction workers: An assessment of contributing factors utilizing fuzzy theory. *Journal of Safety Research*, *85*, 242–253. https://doi.org/10.1016/j.jsr.2023.02.008

Kablitz, D. (2025). Bridging theory and practice with immersive virtual reality: A Study on transfer facilitation in VET. *Education Sciences*, *15*(8), Article 959. https://doi.org/10.3390/educsci15080959

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall.

Kwofie, T. E., Aigbavboa, C. O., & Mpambela, J. S. (2018). Improving continuing professional development compliance among construction professionals through integrated strategies in South Africa. *Journal of Engineering, Design and Technology*, *16*(4), 637–653. https://doi.org/10.1108/JEDT–01-2018-0015

Li, W., Huang, H., Solomon, T., Esmaeili, B., & Yu, L.-F. (2022). Synthesizing personalized construction safety training scenarios for VR training. *IEEE Transactions on Visualization and Computer Graphics*, *28*(5), 1993–2002. https://doi.org/10.1109/TVCG.2022.3150510

Li, X., Yi, W., Chi, H.-L., Wang, X., & Chan, A. P. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, *86*, 150–162. https://doi.org/10.1016/j.autcon.2017.11.003

Loreto, C. D., Chardonnet, J. R., Ryard, J., & Rousseau, A. (2018). WoaH: A virtual reality work-at-height simulator. In K. Kiyokawa, F. Steinicke, B. Thomas, & G, Welch (Eds.), *Proceedings of the 2018 25th IEEE Conference on Virtual Reality and 3D User Interfaces* (pp. 281–288). IEEE. https://doi.org/10.1109/VR.2018.8448292

Makransky, G., & Petersen, G. B. (2021). The cognitive-affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review, 33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Man, S. S., Wen, H., & So, B. C. L. (2024). Are virtual reality applications effective for construction safety training and education? A systematic review and *meta*-analysis. *Journal of Safety Research*, *88*, 230–243. https://doi.org/10.1016/j.jsr.2023.11.011

Manoharan, K., Dissanayake, P., Pathirana, C., Deegahawature, D., & Silva, R. (2023). A competency-based training guide model for labourers in construction. *International Journal of Construction Management*, *23*(8), 1323–1333. https://doi.org/10.1080/15623599.2021.1969622

Misko, J., & Circelli, M. (2022). *Adding value to competency-based training*. National Centre for Vocational Education Research. https://www.ncver.edu.au/__data/assets/pdf_file/0045/9675585/Adding-value-to-competency-based-training_Report-summary.pdf

Mulder, M., Weigel, T., & Collins, K. (2007). The concept of competence in the development of vocational education and training in selected EU member states: A critical analysis. *Journal of Vocational Education & Training*, *59*(1), 67–88. https://doi.org/10.1080/13636820601145630

Nantel, J. (2004). My virtual model: Virtual reality comes into fashion. *Journal of Interactive Marketing*, *18*(3), 73–86. https://doi.org/10.1002/dir.20012

Nasirzadeh, F., Rostamnezhad, M., Carmichael, D. G., Khosravi, A., & Aisbett, B. (2022). Labour productivity in Australian building construction projects: A roadmap for improvement. *International Journal of Construction Management*, *22*(11), 2079–2088. https://doi.org/10.1080/15623599.2020.1765286

Nuwan, P. M. M. C., Perera, B. A. K. S., & Dewagoda, K. G. (2021). Development of core competencies of construction managers: The effect of training and education. *Technology, Knowledge and Learning*, *26*(4), 945–984. https://doi.org/10.1007/s10758-020-09474-2

Oh, H., Yoon, S., & Hawley, J. (2004). What virtual reality can offer to the furniture Industry. *Journal of Textile and Apparel, Technology and Management*, *4*(1), 1–17.

Osti, F., de Amicis, R., Sanchez, C. A., Tilt, A. B., Prather, E., & Liverani, A. (2020). A VR training system for learning and skills development for construction workers. *Virtual Reality, 25,* 523–538. https://doi.org/10.1007/s10055-020-00470-6

Otsuki, M., Ichikari, R., Ohyama, J., Watanabe, H., Endo, H., Takamatsu, N., Okuda, K., & Matsumura, Y. (2023). Exploring visual augmentations for improving the operation of a hydraulic excavator using expert operation replay. In R. Lindeman & H. Whaanga (Chairs), *Proceedings of the 29th ACM Symposium on Virtual Reality Software and Technology* (pp. 376–383). Association for Computing Machinery. https://doi.org/10.1145/3611659.3615681

Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing, 49,* 215–228. https://doi.org/10.1016/j.rcim.2017.06.002

Parong, J., & Mayer, R. E. (2021). Learning about history in immersive virtual reality: Does immersion facilitate learning? *Educational Technology Research and Development*, *69*, 1433–1451. https://doi.org/10.1007/s11423-021-09999-y

Petersen, G. B., Petkakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Computers & Education*, *179*, Article 104429. https://doi.org/10.1016/j.compedu.2021.104429

Renganayagalu, S. K., Mallam, S. C., & Nazir, S. (2021). Effectiveness of VR head mounted displays in professional training: A systematic review. *Technology, Knowledge and Learning*, *26*, 999–1041. https://doi.org/10.1007/s10758-020-09489-9

Riva, G. (2005). Virtual reality in psychotherapy: Review. *CyberPsychology & Behavior*, *8*(3), 220–230. https://doi.org/10.1089/cpb.2005.8.220

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion, 30*(4), 344–360. https://doi.org/10.1007/s11031-006-9051-8

Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics*, *31*(9), 1005–1017. https://doi.org/10.1080/01446193.2013.828844

Schuwirth, L., & Ash, J. (2013). Assessing tomorrow's learners: In competency-based education only a radically different holistic method of assessment will work. Six things we could forget. *Medical Teacher*, *35*(7), 555–559. https://doi.org/10.3109/0142159X.2013.787140

Smith, E. (2010). A review of twenty years of competency-based training in the Australian vocational education and training system. *International Journal of Training and Development*, *14*(1), 54–64. https://doi.org/10.1111/j.1468-2419.2009.00340.x

Söderman, M. (2005). Virtual reality in product evaluations with potential customers: An exploratory study comparing virtual reality with conventional product representations. *Journal of Engineering Design*, *16*(3), 311–328. https://doi.org/10.1080/09544820500128967

Syiem, B. V., & Türkay, S. (2025). A systematic exploration of collaborative immersive systems for sense-making in STEM. *Behaviour & Information Technology*, *44*(13), 3318–3347. https://doi.org/10.1080/0144929X.2024.2441963

Turner, P. (2016). *HCI redux: The promise of post-cognitive interaction* (1st ed.). Springer International Publishing. https://doi.org/10.1007/978-3-319-42235-0

Vahdatikhaki, F., El Ammari, K., Langroodi, A. K., Miller, S., Hammad, A., & Doree, A. (2019). Beyond data visualization: A context-realistic construction equipment training simulators. *Automation in Construction*, *106*, Article 102853. https://doi.org/10.1016/j.autcon.2019.102853

Vasilevski, N., & Birt, J. (2020). Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments. *Research in Learning Technology*, *28*. https://doi.org/10.25304/rlt.v28.2329

√Wang, P., Wu, P., Wang, J., Chi, H.-L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International Journal of Environmental Research and Public Health*, *15*(6), Article 1204. https://doi.org/10.3390/ijerph15061204

Wang, X., & Dunston, P. S. (2007). Design, strategies, and issues towards an augmented reality-based construction training platform. *ITcon, 12,* 363–380. https://www.itcon.org/2007/25

Yoon, B., Kim, H. I., Oh, S. Y., & Woo, W. (2020). Evaluating remote virtual hands models on social presence in hand-based 3D remote collaboration. In V. Teichrieb, H. Duh, J. P. Lima, & F. Simões (Chairs), *Proceedings of the 2020 IEEE International Symposium on Mixed and Augmented Reality* (pp. 520–532). IEEE. https://doi.ieeecomputersociety.org/10.1109/ISMAR50242.2020.00080

Corresponding author: Kate Thompson, kate.j.thompson@qut.edu.au

Please cite as: Thompson, K., Turkay, S., Brown, R., Winter, G., Burden, A., Burland, S., Douglass-Bonner, A., Gallaher, C., Bowler, J., James, A., Lee, C., Bargiel, R., Morrow, C., & Tay. A. (2026). The effectiveness of virtual reality (VR) for construction skills training. *Australasian Journal of Educational Technology*, *42*(1), 56–76. https://doi.org/10.14742/ajet.10693