VIRTUAL REALITY

TRAINING IN CONSTRUCTION

A comparative study of its effectiveness compared to traditional methods

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In 2020, Construction Skills Queensland (CSQ) released a call for proposals for research about the effectiveness of Virtual Reality (VR) compared to traditional approaches to training for construction skills. Members of the QUT research team met with representatives from CSQ and also Next World Enterprises (NWE) and a proposal to conduct research to inform CSQ's understanding of the potential role that VR can play in construction skills training was created. The study was carried out between 2021-2022. A co-design approach to the research design included a stakeholder workshop (with representatives from CSQ and NWE), literature review and resulted in high-level design for research, the VR Training Design Framework, in order to inform the development of the Virtual Training for Work Safely at Heights Research Environment. The Virtual Training for Work Safely at Heights Research Environment was created and used for data collection. In order to determine the effectiveness of VR training and reliability for mass utilisation, we collected data related to learning outcomes (assessment scores and recall, immediately and after one month), the learning and pedagogical design (questionnaires, interviews), and the digital and physical learning environment (logfiles, questionnaires, interviews). Data was collected from 109 participants (n=59, VR group; n=50, non-VR group) from three RTOs in Southeast Queensland. One month after completion of the VR or traditional training, participants were sent a follow up survey. The project team has made recommendations for future research and suggested the use of a checklist for learning design and learning environment to guide decision-makers in the use of VR for a unit of competency. Analysis of the data showed the following findings:

Learning outcomes

1. There was no significant difference between the VR group and the non-VR group for many items when the questions were answered immediately after training.
2. Participants in the non-VR group were better able to describe the steps involved in EWP compliance checking.
3. Participants in the VR group were able to describe the steps leading up to the goal of changing the lightbulb.
4. After a one-month, a retention test showed that there were some differences between the groups, with the VR group scoring better than the non-VR group on some items, and the non-VR group scoring better than the VR group on others.

Learning and pedagogical design

Adopting the principles outlined in the VR Training Design Framework supported the creation of an effective VR Training Research Environment. Key to the success of the VR Training Research Environment were:

1. Providing learners with opportunities to exercise agency in terms of interaction, operation of the EWP and their own learning
2. Learners were provided with a consistent training experience
3. The use of location to provide a structure to learning and provision of feedback through display of correct and incorrect selections
4. The provision of a safe and supportive learning environment – including lower pressure in terms of risk and pace

Digital and physical learning environment

The following were explored through the analysis of data:

1. Visualisation and interaction design provided an engaging and immersive learning experience that was motivating for students;
2. Learners engaged with the onboarding tutorial which provided effective preparation for learners to engage with the Virtual Training Research Environment;
3. There are connections between the requirements of high quality visualisation, interaction design, headsets and other hardware, and the physical learning environment.

Introduction

The Final Report describes the findings of the *Virtual Reality Training in Construction* study and includes recommendations for the design and implementation of Virtual Reality (VR) training in the area of construction skills as well as areas for further research. In 2020, Construction Skills Queensland (CSQ) released a call for proposals for research about the effectiveness of Virtual Reality (VR) compared to traditional approaches to training for construction skills. Members of the QUT research team met with representatives from CSQ and also Next World Enterprises (NWE) and a proposal to conduct research to inform CSQ's understanding of the potential role that VR can play in construction skills training was created. The study was carried out between 2021-2022. A co-design approach to the research design included a stakeholder workshop (with representatives from CSQ and NWE), literature review and resulted in high-level design for research, the VR Training Design Framework, in order to inform the development of the Virtual Training for Work Safely at Heights Research Environment (phase 1). The Virtual Training for Work Safely at Heights Research Environment was created (phase 2) and used for data collection (phase 3). In order to determine the effectiveness of VR training and reliability for mass utilisation, we collected data related to learning outcomes (assessment scores and recall, immediately and after one month), the learning and pedagogical design (questionnaires, interviews), and the digital and physical learning environment (logfiles, questionnaires, interviews). Data was collected from 59 participants in the VR group and 50 participants in the non-VR group from three RTO's in South East Queensland. One month after completion of the VR or traditional training, participants were sent a follow up survey. For the remainder of the report, questions aimed to measure participants' learning outcomes in the follow up survey will be referred as retention or one-month retention.

The project team has made recommendations for future research and suggested the use of a checklist for learning design and learning environment to guide decision-makers in the use of VR for a unit of competency. The results indicated that VR can be as effective as current approaches to training for specific learning outcomes. The effectiveness of VR is directly related to core elements of the learning design as well as the design of the training environment. There are several aspects of the design of this project that differentiate this study within the existing research in this area:

- The participants in most prior studies were students or volunteers, in this study the participants were construction workers who engaged with training;
- Most prior studies measure learning by comparing pre- and post-tests within a group, in this study the learning outcomes of the VR group were compared to identical assessment items of participants who had undertaken traditional competency training and assessment in Queensland;
- Most prior studies focus on the user experience of VR, in this study retention after a delay was also measured;
- The sample size in this study was much larger than preceding studies investigating the use of VR in the construction industry;

This is the first study in the Australian construction industry to test the effectiveness of VR compared to traditional approaches to training, by inviting a large number of construction workers, comparing learning outcomes against industry competency training assessment, and including measures of retention.

Background

In the last decade, VR has re-emerged in the consumer marketplace. 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 technology hardware that provides these experiences come in many forms - from room-sized projector-based systems for multi-user engagement to tangible devices for individuals that allow physical interaction with virtual objects (Davila Delgado et al., 2020).

Along with VR, another emerging technology, Augmented Reality (AR), uses computer-generated simulation and overlays the data onto the real world. AR devices differ from VR devices by augmenting the real environment with visual representations of data instead of simulating a closed VR environment. AR technology allowed for integrating virtual objects anchored into the real world and has been popularised through engagement with mobile device applications and games (Vasilevski & Birt, 2020). The definitions of VR and AR tend to overlap depending on the method of application, and this has created an encompassing term, Mixed Reality (MR) that is defined by the merging of real and virtual worlds, where physical and digital objects co-exist in real-time (Moore & Gheisari, 2019; Vasilevski & Birt, 2020). The emerging technologies of AR, VR, and MR are collectively termed Extended Reality (XR).

VR has re-emerged as a novel but practical technology due to increased computer processing power, graphics, and display technologies (Osti et al., 2020; Parong & Mayer, 2021). One type of VR which uses Head-Mounted Displays (HMD) has advanced alongside 3D gaming (Renganayagalu et al., 2021). What started as a niche in the computer games field has rapidly grown to a viable product for home consumers and other industries for specialised applications. The advent of the current VR systems, using HMD for education and training, has been considered for its potential as an efficient teaching alternative (Vasilevski & Birt, 2020) and provides cost-effectiveness compared to other traditional training methods (Vahdatikhaki et al., 2019; X. Wang & Dunston, 2006). Due to the affordances that VR provides to immersive interaction along with options for spatial head tracking, VR has been investigated with spatial training skills, cognitive awareness, and natural interaction and immersion (Han et al., 2021; Renganayagalu et al., 2021). For this reason, studies with VR often relate to spatial knowledge acquisition skills, such as visual scanning, head movements and observation(Sacks et al., 2013).

VR has had applications in numerous fields - from its initial development for military purposes (Vahdatikhaki et al., 2019; Wang & Dunston, 2006), 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 experience, task performance, retention and engagement (Osti et al., 2020). Table 1 summarises how the research into the use of VR for learning in various areas of construction has developed over time, in relation to both the technology used and the research design.

Table 1: Summary of literature on the use of VR for training in the construction industry

Training context	Year	Technology	Research design	Findings	Reference
Construction Training (Equipment Operators)	2006	Different types of immersive AR	Review of VR/AR training, comparison with standardised training	Construction firms can save time, money, and effort in providing recruit training scenarios in VR/AR Environmental effects minimised, including hazardous and expensive on-the-job (OTJ) operator training Valuable in training for impractical, logistically challenging real-world scenarios	(Wang & Dunston, 2006)
Construction Safety (Environment)	2012	VR	Prototype Construction Environment and use case scenarios including 'do-or-die' consequences. Reviewed by built environment students, academics, and construction industry professionals	Research indicates a strong potential for validation of processes in the VR environment. Feedback states that VR is an exciting supplement to tertiary education. Other participants indicate implications for actions provide implications to real-time decision making.	(Goulding et al., 2012)
Construction Safety (Plant Operation)	2012	3D game-based training program (PC based) with Wii controllers	15 construction workers participating in five construction operation VR scenarios for safety training. Comparison made with traditional training, interviews, and questionnaires.	Comparison indicators show an advantage of VR over traditional methods, particularly safety identification and recognition of plant operations. The study showed little impact on the prevention of safety problems. Performance of safety training presented as better than traditional, especially with collaborative VR scenarios.	(Guo et al., 2012)
Construction Safety (Ironworkers)	2013	Ultrawide Band Location trackers on PPE and construction objects providing real-time data collection and feedback to the participant; Video	Real-time visualisation and tracking of construction workers in indoor training - steel girder rigging tasks and tracking unsafe behaviours; Participant questionnaire	Compared to traditional video recording, tracking data provided advantages with different perspectives and views, identifying incidents, pre-planning tasks. 20% of participants said they did not feel safer using real-time tracking technology.	(Teizer et al., 2013)

		Monitoring; Simulation visualised from captured real-time data.		The ability to replay scenes creates a greater sense of severity in incidents.	
Construction Safety	2015	VR in Second Life (Linden Labs)	20 participants in two groups - 10 in a classroom, 10 in Social VR; Virtual scenarios based on real safety cases, including hazard identification; Questionnaires, and NASA task load index	Preliminary results indicate that VR construction safety has great potential to enhance experiential learning. The in-game scenario was time-consuming to set up and considered complicated by participants. Students had to spend additional time to learn new skills for the scenario tasks.	(Le et al., 2015)
Construction (Engineering)	2018	Desktop-based VR : 17, 26%, Immersive VR : 4, 6%, 3D game-based VR: 4, 6%, BIM-based VR : 31, 47%, Augmented Reality : 10, 15%, **Total : 66, 100%**	A systematic review of Construction Engineering Training and Education; Identifying VR and related technologies, implementations, and future directions	Construction safety training is the second largest application area of VR in Construction Education. VR enhanced learning has potential to help online learners by improving spatial skill and concentration. VR technologies demonstrates benefits depending on how realistic the virtual information is provided in different scenarios. 3D game-based AR and VR have tremendous potential to increase students' participation, interaction, and motivation.	(Wang et al., 2018)
Construction Project Management	2019	Desktop PC BIM-based VR, communicating with HMD VR	220 Students (7 universities); Scenario tasks in BIM and VR; emphasis on communication tools in VR for collaboration; team discussion for data collection following VR.	Strong potential for conducting training in construction and engineering training – specifically teamwork, problem identification and solving, and safety awareness. Efficient feedback loop from this method of VR training has potential to reduce time and financial costs in construction projects.	(Wu et al., 2019)
Construction Training (Heavy	2019	Seated HMD-VR, simulation of mobile construction	Training for heavy equipment operators, using context-realistic simulators.	Framework for next generation training simulators is proposed.	(Vahdatikhaki et al., 2019)

Equipment Operation)		equipment for training; head-tracking device.	Framework proposed, and tested by expert training instructors	Context-realistic VR simulators show potential to improve training simulators. Current tracking and sensing technology enables a wide collection of data for construction environments, items, and actors.	
Construction Training (Health and Safety)	2019	Different types of AR and VR	Systematic review of existing studies, comparisons of computer-aided technology and traditional methods	Computer-aided technology can overcome limitations of traditional tools in training, including: Limited representation of the actual workplace situations, Text-free interfaces to overcome workers with low English proficiency and low literacy, User engagement to attract and maintain trainees' attention is a catalyst to success of training programs.	(Gao et al., 2019)
Construction Training (Wooden Light Frame)	2020	HMD VR	HMD VR vs 2D video	VR resulted in better retention, task performance, learning speed, and engagement than the video training.	(Osti et al., 2020)
Construction Site Planning and Activity Scheduling	2020	HMD VR and BIM technologies	Experienced workers provide feedback in a collaborative setting, and head tracking data collected	VR based space planning showed improved configuration of workspaces in project site plans as well better adherence to safety procedures Improved mutual sharing of information among stakeholders through VR activity and simulation environment	(Getuli et al., 2020)
Construction Learning Environments	2020	Mixed reality (MR) and Mobile MR (MMR)	90 student participants using mobile phone-based AR and VR	MMR in learning can result in enhanced learning environments, unique learning experiences, and engagement for students.	(Vasilevski & Birt, 2020)
Construction	2020	Different types of AR and VR	Systematic review of factors that drive and limit VR and AR in construction	Findings include four grouped factors that drive adoption of AR and VR in construction. Improving performance in projects,	(Davila Delgado et al., 2020)

				Improving companies' images, Improving companies' overall performance, Bolstering research and development.	
Safety training for overhead crane operation	2021	VR vs Desktop computer safety training of procedures in operation of an electric overhead crane.	20 crane operators; 3x experienced, 16 (young) inexperienced, assessed over 5 tasks.	Statistically significant increase in hazard identification capability of operators after VR based training.	(Dhalmahapatra et al., 2021)
Construction Safety Training	2021	VR simulator (tracking devices + wireless VR for accurate limb movement) HTC vive pro	12 Adults, monitoring walking gait through motion tracking to assess postural stability in construction site falls from height.	Experiments showed that VR simulations surpassed traditional methods of evaluating limb stability at heights. This leads to potential improvements in effective fall-related safety training.	(Habibnezhad et al., 2021)
Industrial Training	2021	Systematic review of VR	Systematic review of VR HMD used in specific industry training	VR found to be a good alternative when OTJ training is impossible or unsafe. Evidence to suggest that VR is useful for training cognitive skills, spatial memory, remembering procedures, and psychomotor skills.	(Renganayagalu et al., 2021)

Methodological approach

Learning design

Co-design is an approach that, in education contexts, produces more usable innovations and expands instructors' agency in the process of improving teaching and learning. The model of co-design used here involves the creation of *collaborative* design, and with it, the creation of *transdisciplinary* knowledge that is supported by, and enables *research* about the impact of technology on learning and teaching. It is: *collaborative* because all members of the team contribute to identifying common goals including sources of evidence to monitor the outcomes of the design; *transdisciplinary* because different types of knowledge are brought together in the design of learning environments, pedagogical approaches, the collection and analysis of data, to inform feedback to students, instructors and designers; and enables *research* through the adoption of methodologies, such as design-based research, that combine the design of learning environments with the development of learning theory.

Designing for learning involves uncertainty in terms of predicting how particular designed features of learning environments will play out for different groups of learners. Design frameworks have been created as tools that can help designers maximise the alignment between desired learning outcomes and design. Design frameworks often recommend that designers begin by clearly articulating learning objectives and designing backwards to create tasks that are intended to lead to those outcomes. Alignment between designs, learning outcomes and measures guides the design process. Collecting evidence of those outcomes can help designers gauge their success. The research on educational design teams (see for example Martinez-Maldonado, 2016; Wardak, 2016) shows that tools that allow representations of the design to be co-created and shared, are important in communication of ideas, and continue to support the ongoing collaborative design.

There are various frameworks to help instructors and researchers make sense of the complexity that encapsulates design, learning and teaching. The framework we will adopt for this study is the Activity Centred Analysis and Design (ACAD) framework (Carvalho & Goodyear, 2014). They state that there are four elements (see Figure 1) to consider during *design time* – the social, set and epistemic can be designed (roles and rules; tools and digital and physical learning environment; processes of knowledge building, tasks). The fourth occurs during *learn time* – the co-configuration and co-creation of the learning environment, what actually happens. This framework can be used to guide the design and the establishment of research and design questions, that guide the collection of data, to inform practice (Alhadad & Thompson, 2017).

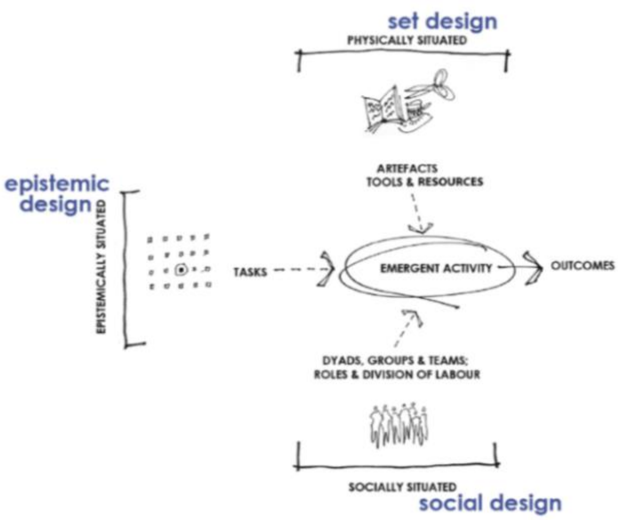

Figure 1: The ACAD Framework

Understanding of the learning situation

QUT facilitated a 1-day design workshop with Construction Skills Queensland and NWE personnel at QUT Gardens Point. The workshop aimed to determine the requirements for the safety training and the potential methods of assessment as well as to identify appropriate content sources for the VR training environment. Following the workshop, QUT created a design framework to assess the effectiveness of VR safety training.

Set design

This process provided an extensive list of equipment considered to support training with VR as well as in traditional approaches - including VR headsets, Wi-Fi, pen and paper, projectors, swivel chairs, PCs, video or books, harnesses. In addition, infrastructure that would be necessary to provide instructors with feedback about learner progress was identified such as biometrics, motion capture and dashboards. Finally, the equipment needed for assessment was described such as tests and observation schedules and checklists.

Social design

The social arrangements described indicated that learning was typically considered to be an individual undertaking with most interactions occurring between the instructor and the learner, rather than collaborative learning.

Epistemic design

Participants identified several stages in the training: induction, theory, practical and assessment. Of note was that assessment includes both multiple choice and written formats as well as observations during the practical component of training. Learners are given feedback and provided with opportunities to revise their contributions. Observations are not standardised, and failure is rare. Tests are open book. The learning environment can be considered as physical simulation, eLearning or classroom with presentation and VR in classroom.

Co-creation and co-configuration of learning

In the classroom, learners sit at desks as they are taken through a presentation and complete a workbook. In the physical environment they watch a demonstration and then demonstrate processes with feedback for the instructor and repetition allowed. In the eLearning situation, learners are self-paced using videos, text, and a test at the end. The VR offering connects theory and practice with a voice-over, autonomous paced assessment on theory throughout.

Stakeholder feedback

An initial design was shared with the stakeholders and CSQ outlined the following goal for the research:

to determine if VR could be used to gain the same level of effectiveness for a unit of competency (or a part thereof) as training as it is currently delivered and assessed.

Based on this feedback as well as the workshop and literature review, the following requirements for the research were identified to be of key importance:

- Face-to-face learning is the most important to test against VR
- Compliance, knowledge acquisition based on existing industry training protocols and procedures is key
- A naturalistic setting for experiments is necessary
- Transfer is of interest to the stakeholders

CSQ provided the following assessment of the availability of participants in three potential learning areas as outlined in Table 2.

Table 2: number of CSQ funded trainees and RTOs for three units of competency

Unit of competency	CSQ funded trainees in 2020	# Trainees in top two training organisations
Hazard Identification	180	35 trainees, 30 trainees
Working at Heights	4,500	800 trainees, 450 trainees
Confined Spaces	2,500	600 trainees, 110 trainees

CSQ identified working as heights as the preferred area of focus for the research study.

Research Design

We implemented a mixed methods approach which, aimed to include approximately 60 participants at one registered training organisations (RTOs). We collected data from 109 participants (VR group = 59, non-VR group = 50) at three RTOs. CSQ provided the researchers with appropriate RTOs to approach. Quantitative data was collected from questionnaires and assessment protocols for the unit of competency, and qualitative data from interviews. In addition, we collected interaction data from the learning environments as well as data from participants related to affective experiences. In the experimental design we identified research questions (related to the relationship between the use of the different types of technology and learning outcomes) and design questions (related to the utilisation of the technology or the design of the learning environments related to immersion).

Research and Design Questions

The overarching research question identified in the Milestone 1 report was:

How effective is VR in training for a unit of competency in comparison to traditional methods?

The sub-questions are:

RQ1: What is the impact of agency on learning outcomes?

RQ2: How does physical location in the virtual environment influence learning outcomes?

RQ3: How does immersion impact learning outcomes in relation to construction skills?

RQ4: How does the immersiveness of the learning environment influence what learners learn one month after their learning experience?

We also identified questions related to the design of VR for construction skills training:

DQ1: How reliable is the technology for mass utilisation?

DQ2: How does feedback to the learner impact learning outcomes?

The initial research design proposed in the milestone 1 report is presented in Table 1, below.

Table 3: Initial experimental design

Working at heights		
Learning environment: traditional		
Educational design	Theory	
	20 participants	
Learning environment: VR		
Educational design	Theory	
	Immediate feedback	Post feedback
	20 participants	20 participants

The design outlined in Table 3 was proposed to allow us to compare:

- dependent variables in relation to classroom and VR learning environments in relation to the role of theory and practice in learning about working at heights
- dependent variables in relation to VR learning environment and feedback.

During the data collection phase, two changes were made to the initial design (1) the non-feedback condition was discarded and (2) the follow-up questionnaires were sent after one month only. Neither of these are expected to have an impact on the ability of the research to provide responses to the research and design questions.

The post-feedback condition was discarded in order to ensure that the data collection was conducted in a way that supported effective use of participants' time. The research training environment was created so that feedback on progress was given by the research assistants running the study (not within the system). This was done so that the research training environment could replicate the traditional environment as accurately as possible (in the traditional environment, instructors will provide students with feedback about their progress). The original design was for the two research assistants carrying out the data collection at the RTO would give this feedback consistently to all participants in that condition. The research assistants were trained in giving the different types of feedback (about using the VR equipment to interact with the training environment, as well as about the adequate demonstration of the necessary skills). However, when the research assistants began carrying out the data collection, they found that the participants who were in the post-feedback condition were unable to progress through the research training environment without feedback on their progress. These participants who did not receive feedback were then likely to stop participation and not complete the final interview. Given that the data generated from their participation would ultimately, therefore, not be able to be included in the analysis, rather than persist with this approach, it was decided that all participants would be given immediate (consistent) feedback about their progress through the research training environment. Participants continued to ask for feedback at the additional RTOs at which data collection took place. The analysis of the interactions with the research training environment provided us with data related to feedback in the final analysis.

The follow-up questionnaires were sent after one month instead of after one week as well as one month because the team was concerned that the participants were already being asked to complete a number of questionnaires and were not confident that participants would complete a questionnaire after one week. Given that participants also undertook training for other areas during this time, the potential for recall after only one week was low. Therefore it was determined that one month would provide participants with a break from answering questions and provide compelling data for the research question regarding recall after participating in the study.

Table 4: Final experimental design

Working at heights	
Learning environment: traditional	
Educational design	Theory + Practice
	20 participants (n=50)
Learning environment: VR	
Educational design	Theory + Practice
	Feedback
	50 participants (n=59)

Work Safely at Heights Training Scenario Development

After the initial analysis of the first phase of this project, members of the research team worked with CSQ to identify and recruit an RTO in Brisbane to participate in the research project. A selection of RTOs was provided by CSQ and the QUT research team met with representatives from each. RTO-A is a company based in the south of Brisbane, responded positively and engaged with the research team, agreeing to provide access to the team to undertake data collection at their training centre.

The QUT team observed a training session on at heights training at RTO-A that incorporated training on platforms at height. While watching the training with a scissor lift, it was decided that training for work safely at heights would be an appropriate focus to investigate the potential role of VR in training. The following aspects of the implementation of VR for training were considered in arriving at this decision:

- availability of large areas needed to accommodate free movement when engaging with VR
- time required to create the detailed feedback required to consider areas such as handing harnesses over to other workers
- approaches to physical interaction with the virtual environment – including joystick – and how these aligned with the face-to-face training experience
- impact of the creation of authentic experiences of aspects of working at heights on the ability of the research to provide meaningful results in the comparison of face-to-face and virtual training experiences
- elements of the face-to-face training experience that were essential to achieving intended learning outcomes.

The design of the virtual training for work safely at heights research environment was informed by site visits, communication with project stakeholders (including CSQ, NWE, and RTO-A), and the documentation provided. Training documents, including PowerPoint slides, pdfs for tests and related elements were gathered, curated for selected comparison elements, providing information for the design of the virtual training for work safely at heights research environment. As the documentation was sourced from an accredited RTO, it is assumed that this meets compliance requirements against Australian training standards. In the following section we describe the design of the virtual training for work safely at heights research environment.

VR Training Design Framework

The VR Training design framework uses the ACAD framework to align the affordances of VR with the locations and scenarios to identify design principles for the creation of VR for construction skills training. These elements of the design are considered key to understanding the results of the research carried out. In this research, we assume that learning is experiential, embodied, and situated.

Immersive environments like VR support these types of learning, offering unique and engaging experiences. Experiential learning is a well-known theory in education. Kolb (1984) describes 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 refers to a holistic approach that emphasises how experiences, including cognition, environmental factors, and emotion impact the learning process. Embodied learning is a pedagogical approach that emphasises the role of 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). 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).

Table 5: VR Training Design Framework

Location	Description	Purpose	ACAD	Design principles
Site office	Tutorial about the controller and user interactions, how to navigate the user interface and how to select and use objects within the virtual environment.	Training for the use of the tools within the VR environment.	Set	Participants must understand how to use the tools available to them.
Site office	Activate and apply any safety clothing and accessories as required by the work site, such as hard hat, high-vis vest, boots, and other necessary items.	Agency	Set/ social	Participants should be encouraged to adopt a role/persona in the VR environment.
Location 1 (not at height)	Step-by-step instruction about the procedure for identifying work requirements/ work procedures and instructions.	Training for processes of working at heights.	Task	All participants should be presented with a consistent training experience with clear steps to follow.
Location 1 (not at height)	Participants are not able to move to the next task until they have demonstrated they can complete the steps correctly.	Training for processes of working at heights.	Task	Participants should be allowed to repeat a task until they can demonstrate that they can complete it correctly.
Location 1 (not at height)	Identify anything in the work area that should be addressed and perform the appropriate procedures.	Training and demonstration of practical skills.	Task/set	Participants should be given multiple opportunities to demonstrate their understanding.
Location 2 (at height)	Identify anything in the work area that should be addressed and perform the appropriate procedures.	Training and demonstration of practical skills at height.	Task/set	Participants should have the opportunity to connect theory and practice in an authentic and safe environment

Design of the virtual training for Work Safely at Heights research environment

The design of the virtual training for work safely at heights research environment has been informed by the Activity Centred Analysis and Design (ACAD) framework (Goodyear & Carvalho, 2014). As described above, the team drew on the documentation provided by RTO-A to ensure that the design of the research environment was aligned with the identified learning goals. This was essential given the goal of this project is to compare learning outcomes from the virtual environment with those achieved in the face-to-face environment. The VR experience was constrained to 20 minutes (with an additional 10-15 minutes allocated for data collection related to completion of questionnaires). This would better allow the intervention to be accommodated in the schedules of the trainees.

A description of each stage of the virtual training research environment is outlined below. Each stage is mapped explicitly to elements of RTO-A's training content, includes the location, the learning intentions, and a description of what the user is expected to do. These design documents were then used to develop the virtual training for work safely at heights research environment. The user interface elements of the design (such as narrative elements and VR controller mappings) have not been included in this part of the report but can be viewed explicitly in the figures and the video provided.

Onboarding Tutorial

RTO-A Training Mapping

The purpose of the onboarding tutorial is to provide an introduction to the VR controls and is not intended to prepare users to work safely at heights.

Location

Warehouse – There is a table near the wall (Station #01). This area is used to introduce the trainee (user) to the virtual environment and to learn to use the handheld controllers while wearing the headset.

Learning Intentions

- Onboard beginner to intermediate VR users to the virtual environment.
- Practice holding and using controllers and headsets.
- Make connections between actions in the physical and digital environments.
- Ensure all participants have used VR system before beginning the training.
- Understand the functions of the checklist / tasks to be completed.

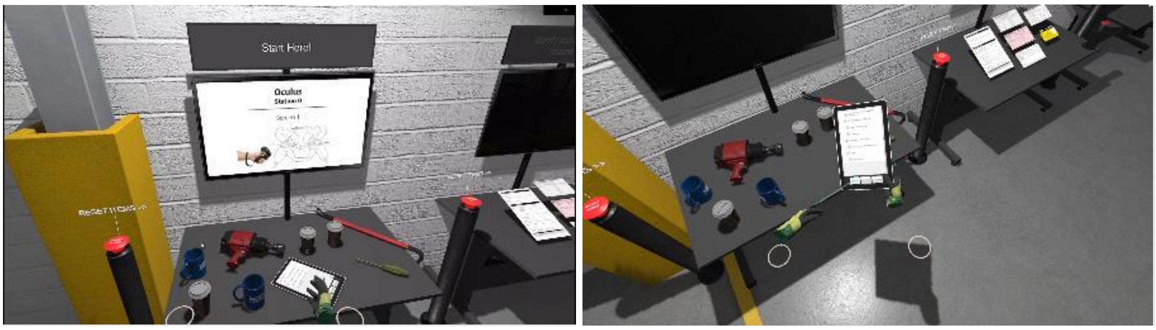

Figure 2 Images showing familiarisation tasks for hand interactions (left) and the display system showing Job Tasks, Narrative Log and World Task status.

Identify and Confirm Work Requirement

RTO-A Training Mapping

RIIWHS204E – ASSESSMENT 1a (p.13) – Inspect the Site and Identify (Potential) Hazards

Location

Warehouse – There is another table next to the tutorial station (Station#02). This contains four documents to review prior to beginning the work task.

Learning Intentions

- Understand the task to be undertaken – using an EWP to change a lightbulb on the factory ceiling.
- Review the documents that need to be considered before beginning the task.

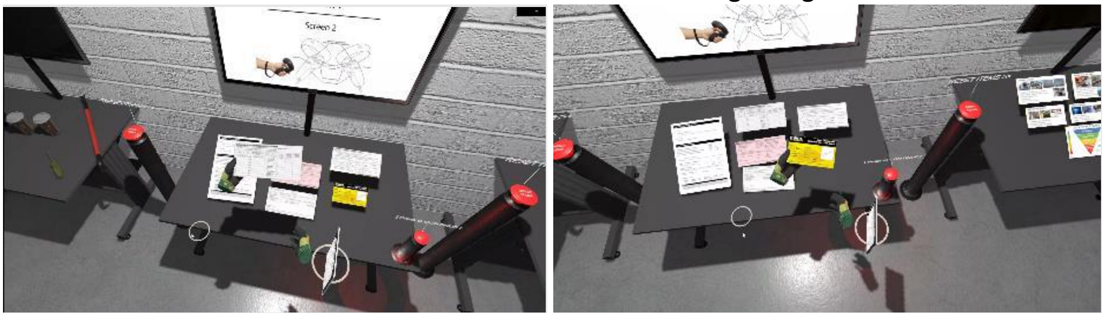

Figure 3 Document analysis station.

Inspect the Site

RTO-A Training Mapping

RIIWHS204E – ASSESSMENT 1b (p.14) – Inspect the Site and Identify (Potential) Hazards

Location

Warehouse – this is a separate area to the tutorial that contains the scissor lift and activity area in which the user will change the lightbulb (Station #03). Note, this is a preliminary observation of the site to familiarise the trainee with the work area.

Learning Intentions

- Learn to inspect the environment (overhead/eye-level/ground hazard).
- Identify and control hazards before beginning work.
- Carry out the correct procedure for creating an exclusion zone.
- Follow hierarchy of control.

Figure 4 site inspection

Select + Inspect Materials, Tools + Equipment

RTO-A Training Mapping:

RIIWHS204E – ASSESSMENT 1c – Select and Inspect Materials, Tools and Equipment

Location

Warehouse – user will find PPE equipment required for the task at Station #04. The required equipment is listed on their tablet. They will reference and place the correct PPE on the mannequin.

Learning Intentions

- learn to reference job plan for PPE information.
- Implement personal safety by wearing the correct PPE for the job task listed.

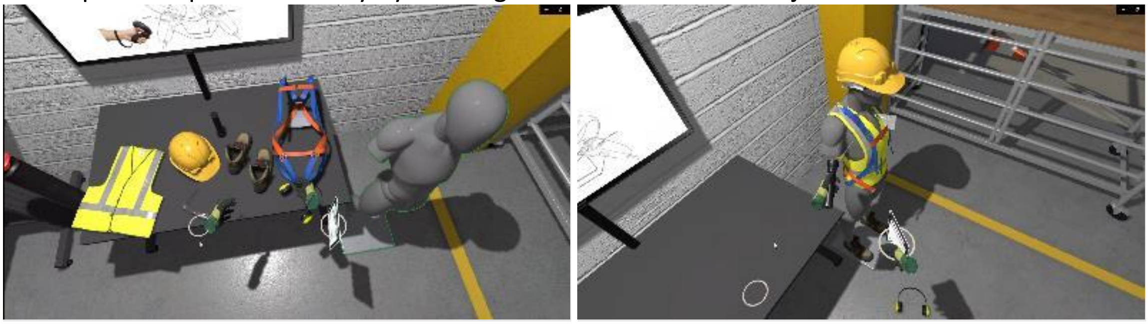

Figure 5 We see the table of PPE with the undressed mannequin (left) and the mannequin dressed with the required PPE (right) in this case, helmet, vest, glasses, boots and torch.

Harness Check

RTO-A Training Mapping

RIIWHS204E – ASSESSMENT 1d – Select and Inspect Materials, Tools and Equipment

Location

Warehouse – user will move to Station #05 to perform harness safety check.

Learning Intentions

- understand need for habitual safety inspection of harness for at heights work.
- understand components of the harness to be checked before use on designated task or sending out to repair/discard.

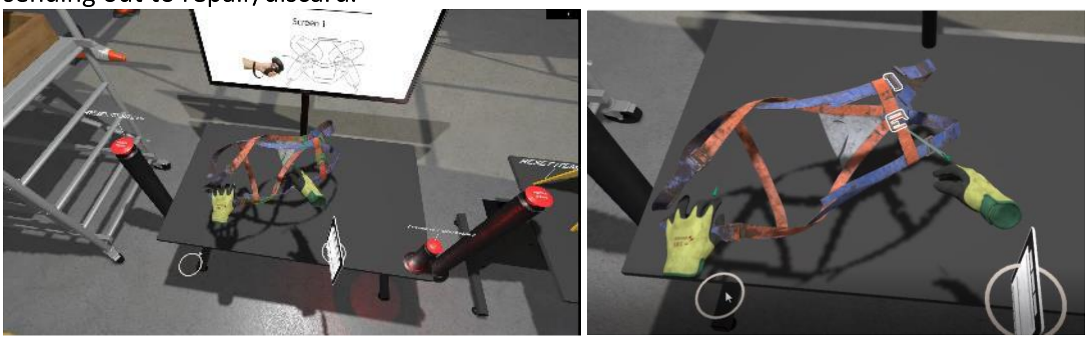

Figure 6 Images showing the harness examination process at the station (left). On the right we see the trainee highlighting and selecting the broken D-Ring (right).

Prepare and Access the Work Area

RTO-A Training Mapping:

RIIWHS204E – ASSESSMENT 1d – Select and Inspect Materials, Tools and Equipment

Location

Warehouse – user will find placards required for the site preparation task at Station #06. They will reference and place the signs in required areas of the warehouse.

Learning Intentions

- implement decisions previously made.
- think of other site users.
- communicate aspects of working at heights.

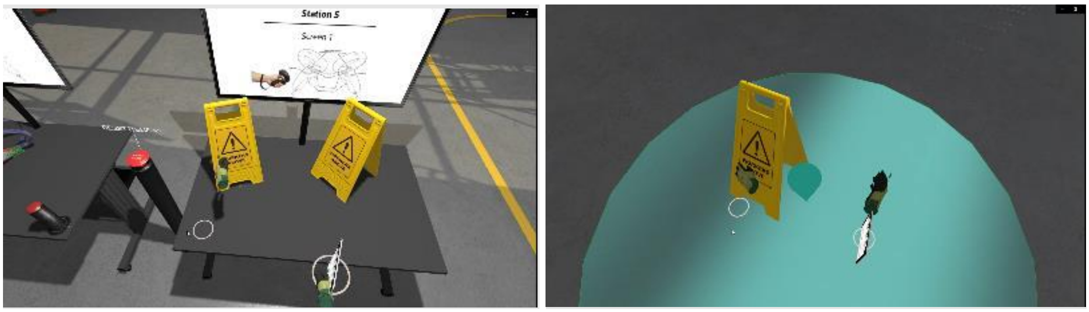

Figure 7 trainees select placards at a station (left) and are guided to placement locations at large circles on the ground (right).

Work Safely at Heights (viz. Performing the Worklist Task)

RTO-A Training Mapping:

RIIWHS204E – ASSESSMENT 1e – Select and Inspect Materials, Tools and Equipment

Location

Warehouse – user will move to Station #06 to (1) select tools, (2) check the elevated work platform and (3) operate the elevated work platform (scissor lift).

Learning Intentions

- learning to predict and identify equipment, tools and materials needed for the job.
- check the equipment and safely finish the task.

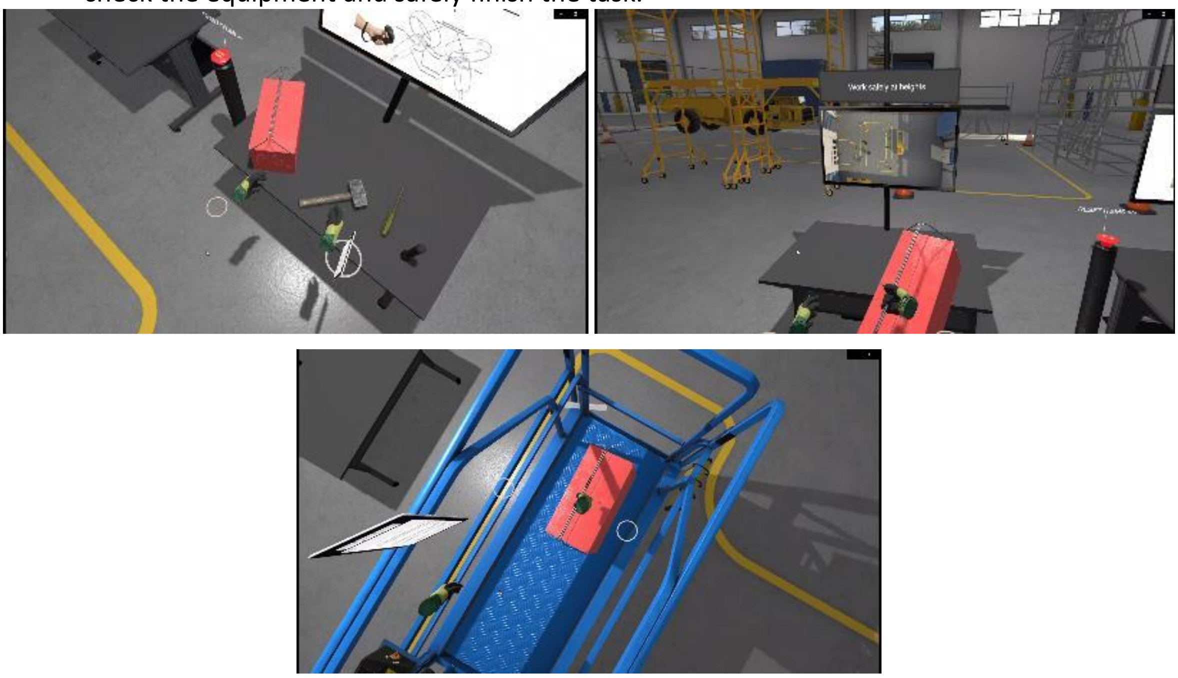

Figure 8 Series of images showing tool selection station (top left), packaging into toolbox (top right) and finally placing the toolbox onto the scissor lift (bottom).

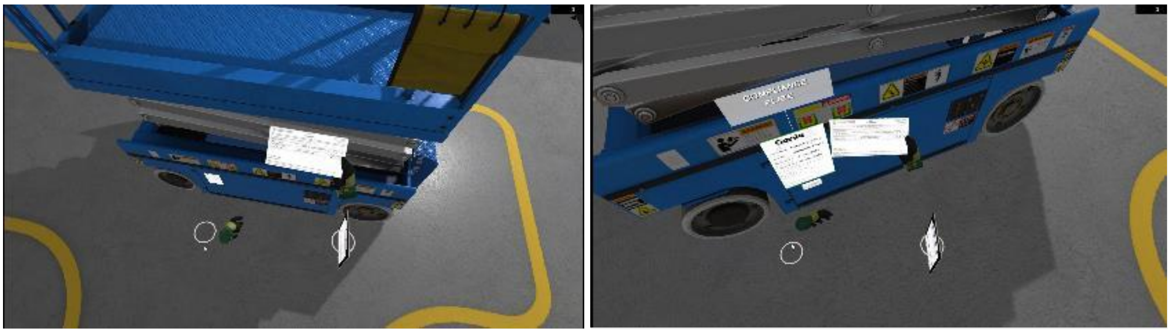

Figure 9 Images of trainee comparing logbook certificate in pouch on lift (left image) with safety certificate on the machine (right).

Figure 10 Using the scissor lift to traverse the environment to perform the task.

Clean Up

RTO-A Training Mapping:

RIIWHS204E – ASSESSMENT 1e – Select and Inspect Materials, Tools and Equipment

Location:

Warehouse – user will exit scissor lift placing tools back at station #07 and will remove signage from previously deposited locations.

Learning Intentions:

- Clean up work area debris.
- Leave a safe environment for others.

Figure 11 finalisation images from the training system showing the parking of the scissor lift and placement of tools at station table.

System Development

Hardware Software Platform Details

After creating and documenting the intended VR training plan, software development processes were commenced to create the virtual training for work safely at heights research environment. Validation experiments between computer systems requires high quality implementations to provide reliable experimental results. To ensure that the results of the comparison between face-to-face and virtual environments in this experiment are as reliable as possible, the research team has created a high-quality training experience. Elements that have been established in the virtual training for work safely at heights research environment include a high-quality large-scale warehouse model, a detailed highly interactive scissor lift and the establishment of high-quality animations with interactive items such as PPE (see Figure 1 and Figure 2). Previous research has shown that such elements as level of detail (Harman 2019) and realistic hand representations increase a sense of presence in virtual reality (Yoon 2020), improving the cognitive outcomes and levels of engagement in the content (Petersen, Petrakis & Makrasnsky, 2022). The system has been implemented in the Unity[1] game engine, using the HurricaneVR[2] and Hexabody frameworks[3].

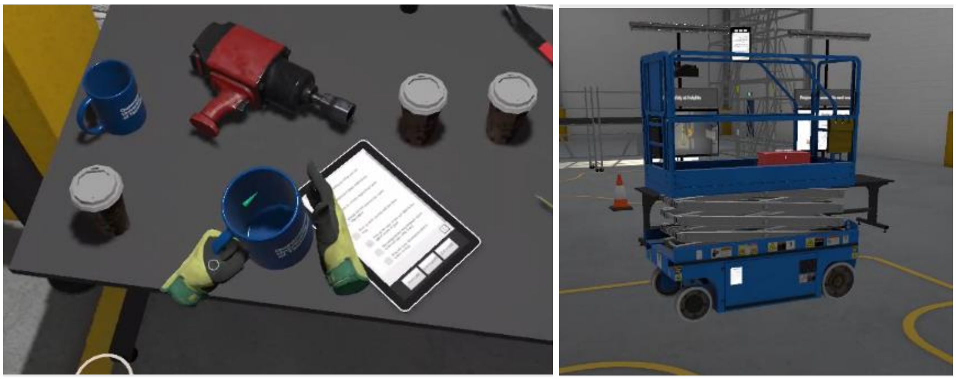

Figure 12 highlighting important visual elements such as animated hand movements (left) and high-quality models (right).

Meta Quest 2 headsets[4] were selected to facilitate easy movement by avoiding restrictive tethers. Running the VR software on the Quest headset itself would introduce quality restrictions that could interfere with experimental results as previously discussed. 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 Quest headset, (see Figure 13 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.

[1] www.unity3d.com
[2] assetstore.unity.com/packages/tools/physics/hurricane-vr-physics-interaction-toolkit-177300
[3] assetstore.unity.com/packages/tools/physics/hexabody-vr-player-controller-185521
[4] www.oculus.com/quest-2/

Figure 13 Example hardware setup at RTO. Note the lack of tether to the headset and high-speed internet router (crown like device on the table) streaming the VR experience to the headset.

Software System Details

A VR training system was developed from the training elements obtained from the RTO and listed in earlier sections. The VR application contains several phases in sequence presented as a sequence of stations, viewed in the video included with the submission of this milestone report.

User Testing Procedures

After a functional prototype was developed it was tested with the RTO, QUT staff and students.

Figure 14 image of user testing at RTO with training staff who deliver at heights training.

RTO Staff Testing

The prototype was taken to RTO-A for assessment. Two training staff who deliver the RIIWHS204E – Work Safely at Heights, ran through a prototype of the system which contained the training stations as detailed in the previous section. They confirmed that the experience was congruent with their lesson plans at the RTO and that the experience is a "good 10-15 minute introduction to using elevated platforms." This is important, as such a confirmation enables the effective comparison of the VR experience with their face-to-face lesson approaches.

QUT Testing

In addition to testing the VR training system at RTO-A, the QUT research team performed user testing at QUT with six staff and students.

Figure 15 Example images of testing at QUT.

Key findings from these user testing sessions were prioritised and delivered to the development team to be addressed in development. The final environment was then created.

Participants

Between June 3rd, 2022 and August 23rd, 2022 data was collected at three RTOs in South East Queensland: RTO-A, RTO-B and RTO-C. 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.

Procedure

Data Collection Equipment

Each data collection session required a PC, and an Oculus Quest 2 Head Mounted Display (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.

Data Collection instruments

The following data was collected:

- pre-training questionnaire to collect background information about the participant (e.g., trade, self-rated experience, ESL, literacy, education level, age, gender)
- observations of what participants do while they participate in each condition
- assessment protocols for theory and practical components
- post-training questionnaire immediately after participation for recall of the experience and user experience
- post-training interviews immediately after participation
- post-training questionnaire one month after participation for recall of the experience.

Table 6: Data collection

	Topic of interest	Research Question
Pre-training: Questionnaire (1)	Background information e.g., trade, self-rated experience, ESL, literacy, education level, age, gender	
During training: Process data	Time on task, interaction with assets, eye-tracker, movement, heart rate monitor	*RQ2: how does physical location in the virtual environment influence learning outcomes?* *RQ3: How does immersion impact learning outcomes in relation to construction skills?*
Assessment protocols for theory and practice	Knowledge acquisition	*RQ2: how does physical location in the virtual environment influence learning outcomes?* *RQ3: How does immersion impact learning outcomes in relation to construction skills?*
Immediately post-training: Questionnaire (2)	Recall of experience, learning outcomes, feedback, realism of the testing environment, agency within the testing environment, interactivity of the assets	*RQ4: Does the immersiveness of the learning environment influence what learners remember immediately after their learning experience?*
Post-training: interviews	User experiences	*RQ1: what is the impact of agency on learning outcomes?*
Post-training: Questionnaire (2)	Difficulty, enjoyment, intrinsic motivation inventory (task-based motivation), sense of presence, and how immersive they felt the environment was.	
One month post training: Questionnaire (3)	Recall of experience, learning outcomes, feedback, realism of the testing environment, agency within the testing environment, interactivity of the assets	*RQ4: Does the immersiveness of the learning environment influence what learners remember one month after their learning experience?*

The following provides a description of the data collection instruments.

Usability questionnaire

Using a 5-point likert scale (1-not at all, 5-Completely), participants rated specific aspects of the VR training in five items: “I could see the images clearly”; “I could read the text clearly”; “I could hear and understand the voice narrator”; “I could interact with the display in a straightforward way”; “I could move around easily.”

Sense of presence – iGroup Questionnaire

Participants’ sense of presence was measured by using iGroup Presence Questionnaire (IPQ). The IPQ comprises 14 items on a 7-point Likert scale (“strongly agree” to “strongly disagree”), which add up to three scales: (a) “spatial presence” assesses the physical sense of actually being in the virtual environment (e.g., “I felt present in the virtual space”); (b) “involvement” evaluates the amount of attention focused on the virtual stimuli (e.g., “I was completely captivated by the virtual world”); and (c) “realism” reflects the participant's perception of the virtual environment as real and believable (e.g., “The virtual world seemed more realistic than the real world”).

User Satisfaction Evaluation Questionnaire (USEQ)

We used a modified version of 5-point Likert scale questionnaire with five items to evaluate users' satisfaction of the VR training (Gil-Gómez et al., 2017). The questionnaire included items such as "Were you successful using the system?" and "Is the information provided by the system clear?"

Enjoyment - Intrinsic Motivation Inventory (IMI)

Participants' enjoyment was measured using the enjoyment scale items from the Intrinsic Motivation Inventory (IMI; Ryan, Mims, and Koestner, 1983). This scale has seven, 7-point Likert scale items (1 - Not at all; 7 - Extremely) that ask the player to indicate how much they agree with a statement (e.g., ”I enjoyed doing this activity very much.”, ”This activity was fun to do.”).

Simulator sickness

In a 5-point Likert scale question ranging from 1-not at all to 5- extremely, participants were asked whether they experienced any cybersickness during the training “During your VR experience, did you have any symptoms of simulator sickness (e.g., nausea, dizziness, headache, blurred vision, vertigo, dizziness)?” If they selected any option other than Not at all, they were asked to specify what they felt.

NASA Mental Load

To measure the extent of mental load VR training caused, participants filled out the 6-item NASA Mental Load scale (Rubio, Díaz, Martín, & Puente, 2004). Example items include “How mentally demanding was the task?” “How physically demanding was the task?” Participants would use a slider between zero and 100 to respond to the questions.

Player Experience of Need Satisfaction Questionnaire (PENS)

To measure participants' sense of autonomy and competence, 3 items from the Player Experience Need Satisfaction Questionnaire (PENS; Ryan, Rigby, & Przybylski, 2006) were used. The questionnaire has a seven point scale (1- Not at all; 7-To a great extent) that ask the participants to indicate how much they agree with a statement.

Recall questions

Participants were asked ten questions to measure their recall from the VR training. These questions were adapted from RTO-A's theory and practical assessment.

The theory questions were about hazards, personal protective equipment, and operating the EWP.

Q1: What is a hazard?

Q2: What are three controls of hazards, from most to least effective?

Q3: What is a PPE?

Q4: What are the three types of PPE?

Q5: What are three types of fall prevention devices?

Q6: What two things do you need to do to check the safety harness and equipment?

Q7: Where should all the tools and equipment be when in the EWP basket?

Q8: What 4 things should you do when operating the EWP?

Q9: What should you do before you lower the platform?

In addition, participants were asked to describe the steps in as much detail as they could that they go through to carry out work at heights safely. Example work: Change a lamp at a large warehouse.

These were evaluated based on the assessment checklists to operate the EWP.

1) Select tools and equipment based on task requirements, including:
    a. Safety equipment (harness, lanyard, absorber).

    b. Inspecting tools and equipment for serviceability and managing faults.
2) Platform checks on the EWP, including:
    a. Pre-start checks.
    b. Operational checks.
    c. Reporting any faults found and isolating the equipment.
3) Set-up the EWP for operations, including:
    a. Assessing ground conditions for a suitable position.
    b. Stabilising EWP.
    c. Using approved safety devices to isolate the work area and protect the surrounding area
    d. Securing tools and equipment in the EWP basket or platform.
4) Operate the EWP.
    a. Respond to monitoring systems and alarms
    b. Recognize and respond appropriately to hazardous and emergency situations as they arise during operations.
    c. Complete work in accordance with the work plan.
5) Park and shut down the EWP and secure outriggers (if fitted).
6) Carry out post-operational checks on the EWP and respond to any faults identified.
7) Complete housekeeping procedures after operations, including
    a. Clearing the work area and disposing of materials
    b. Clearing, checking, maintaining and storing all plant, tools, and equipment.

Semi-structured interviews

Once participants completed the survey, they were asked a set of questions (see below) to further understand their experiences with the VR training.

1. What is your name?
2. Have you done working at heights training before?

There were two sections to this interview – the first section included questions about the feedback you received during your VR training and the second section included more general questions about the VR training environment.

3. Feedback: Feedback is when someone lets you know whether you've done something correctly or incorrectly, and how you could do it differently.
    a. Can you tell me about the feedback you received from the research assistant and within the VR (Virtual Reality) training environment?

[if has done physical working from heights training]: how did the feedback you received during VR training compare to the feedback you received from physical training

[if has not done physical working from heights training]: how did the feedback you received during VR training compare to the feedback you receive from a real job site

[If has done physical working at heights training]:

4. How did this compare with your experience of working at heights training previously?
5. What was better about the VR training environment?
6. What was worse about the VR training environment?
7. VR Training Environment
8. Can you describe what you did in the VR training environment?
9. What did you like the best about the VR training environment?
10. What would you change if you were in charge of the VR training environment?
11. Is there anything else you would like to share with the research team?

Data Collection Procedure

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.

1. *Introduction (1-2 minutes)*

Researchers 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 QUT Ethics Committee and agreed by typing their full name on the consent form to participate in the study.

2. *Pre-survey (3-5 minutes)*

Participants filled out a short questionnaire on their demographics (age, gender, level of education, occupation), prior EWP training experience, and on their familiarity with VR and videogames.

3. *VR training simulation (20 minutes)*

Participants completed the training using the Oculus Quest 2

4. *Post-survey (10 minutes)*

The post survey included usability, user experience and recall questions. Final open-response recall questions were asked and recorded by the RAs to ensure that typing skills were not a contributing factor to the final scores.

5. *Post-interview (5-10 minutes)*

Participants were asked 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.

Data Collection Locations

RTO-A

RTO-A was the main data collection site. Multiple approaches were used to recruit participants. Initially, people who had registered for training would receive a notification within their training reminder email to inform them about the study and provide a link to sign up. However, after about ten days it was determined that this method was ineffective. After that, the trainers announced the study to the classes and would let the research assistants (RAs) know if anyone volunteered to participate. The RAs would then go to the training centre to collect data during the participants' break. This was also determined to be an ineffective method of recruitment. The final method used was for the RAs to go in on the training days and make announcements to the participants themselves. This method was more effective and was used until the end of the data collection. All the participants in the non-VR group were from RTO-A (50) and 28 were recruited to participate in the VR group. Participants in the non-VR group engaged in the RIIWHS204E training which takes 6 hours including both theory and practical aspects.

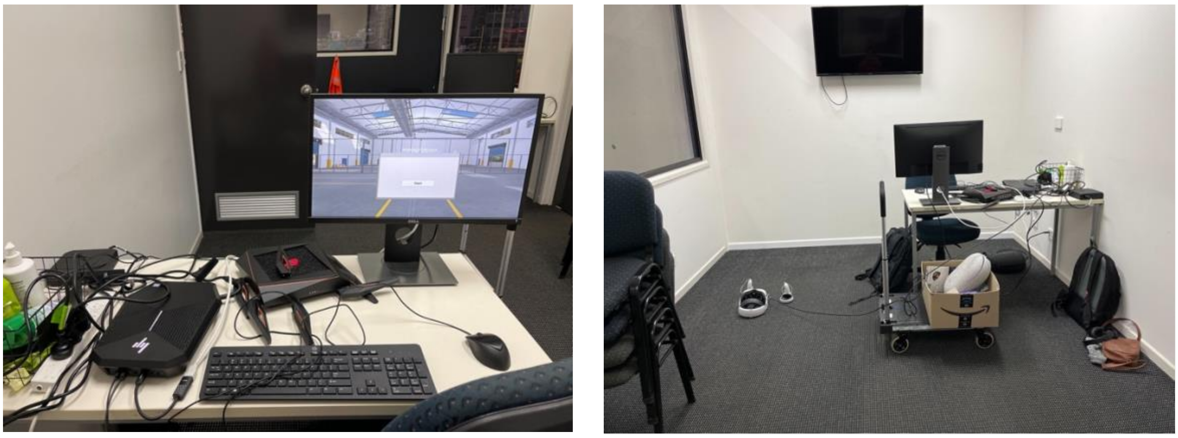

Figure 16: The data collection room and set up at RTO-A

RTO-B

The recruitment at RTO-B involved the manager organizing three afternoons for the research team to set up their equipment and collect data. The manager recruited participants for the research team. Across three training sessions, 16 people participated in the VR training simulation.

Figure 17: An image from RTO-B data collection session. The participant in the front is inspecting the EWP documents in the VR training. The participant on right is taking the post survey. The participant at the back is being introduced to the VR controls.

RTO-C

The process at RTO-C was similar to that at RTO-B. The RTO recruited the participants and the data collection was carried out on site. An additional 16 participants were recruited.

Ethics Approval

The QUT research team obtained ethics approval for this experiment from the QUT Ethics Review committee – Ref Number LR 2021-4545-6162

This included permission to use our designed:

- data collection tools including questionnaires and interviews for participants, assessment instruments, and observation protocols

- information sheets and consent forms for participants
- participant recruitment via an RTO.

The details of the ethics approval application were drawn from the Milestone 1 report. Full ethics documents are not included with this report but are available on request.

Data Analysis

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), and interviews and open-response data analysed using thematic analysis.

Results

In this section we will provide an overview of the participants in the VR and non-VR groups. The results of the comparison of the VR and non-VR group with respect to the assessment of learning will be presented first, then the results of the long term retention assessment. Interaction data, extracted from logfiles generated by the VR Training Research Environment are then reported, followed by the results of the usability and user experience questionnaires. Finally the analysis of the semi-structured interviews is presented.

Participants

Of the 59 participants in the VR group, 41 participants completed all the five steps of VR data collection. The others could not due to various technical issues at RTO-A. One participant at RTO-B did not complete the VR training completely due to the technical issue related to HMD he was using. However, he had gone through several check points in the VR training so he filled out the post survey and answered the interview questions. 32 participants from the VR group answered the retention survey. All 50 students in the non-VR group were recruited from RTO-A. For these participants we only collected their assessment scores.

Table 7: Number of VR group participants at each RTO

	N (VR training)	N (one month retention)
RTO-A	28	10
RTO-B	16	12
RTO-C	15	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, 6 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 construction industry. These included: boilermaker, carpenter, operations technician, electrician, builder, pallet racker, structural engineer, estimator, operational manager, and administrator.

We asked participants whether they had a prior working at heights training. 53 had undertaken training before. Of those who had completed training, 17 had participated in one training session, 6 had participated in two, 2 had participated in three training sessions, one had participated four times, two had participated five times and one of the participants had undertaken working at heights training more than six times.

We asked participants how familiar they were with virtual reality. They rated their familiarity on a 5-point Likert scale (M=2.2, SD=1.08). Only four people reported being very familiar or extremely familiar with VR. The latter participant owned their own head mounted display (HMD). 35 participants reported being not at all or slightly familiar with VR. The remaining 20 stated that they were moderately familiar with VR. Given the relationship between videogame and VR experiences, we also asked how familiar participants were with videogames. The average was 3.24 (SD=1.09) which means they were moderately familiar with videogames. 28 participants reported they did not play videogames weekly. 17 said they play 1-3 hours a week, and 8 participants reported playing 4-6 hours a week. Only five played 7 or more hours a week.

Assessment of learning

Participants' learning was assessed using a set of recall questions outlined earlier both immediately after the VR-training, and one-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 a month after their training. These responses to the assessment questions were scored by a research assistant using an answer key provided by the RTO.

Immediate assessment of learning

Theory: 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.

Table 8: Hazards and the elimination of hazards, immediate assessment – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
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

For the Q1, most answered it correctly (see Table 8) and there was no significant difference between the groups (t = -.92, p=.36). This was similar for the Q3 which was scored out of 3. There is no significant differences between the groups on how they answered this question either, (t=-1.06, p-.29).

Theory: PPE

We found no significant difference between the groups on how they answered the questions related to personal protective equipment (PPEs).

Table 9: PPE, immediate assessment – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Q3	VR	42	.88	.33	.05
	non-VR	47	.96	.20	.04
Q4*	VR	43	2.95	.21	.03
	non-VR	23	3.00	.00	.00

**Q4 (examples of PPE) was removed from the RTO-A assessment at some point so we don't have responses to that question from everyone.*

Most people in each group could define the role of PPE (t=-1.3, p=.197), and could list three types of PPEs (t=-1.04, p=.301).

Theory: Fall prevention devices and harness inspection

We found no significant differences between groups how to inspect the harness (t=1.01, p=.31).

Table 10: Fall prevention devices and harness inspection, immediate assessment – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Q5	VR	42	2.31	.92	.14
	non-VR	43	2.98	.15	.02
Q6*	VR	43	1.37	.49	.08

	non-VR	24	1.25	.44	.09

***Q6 (checking the harness) was removed from the RTO-A assessment at some point so we don't have responses to that question from everyone.**

Participants in the non-VR group could identify significantly more fall prevention devices compared to the VR group (t = -4.62, p<.001). However, this might be expected as there was no explicit teaching of this knowledge in the VR training scenario.

Where should all tools and equipment be when in the EWP basket?

There was no significant difference between the groups for the item related to the tools needed for EWP operation.

Table 11: Tools and equipment, immediate assessment – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Q7*	VR	41	.96	.13	.02
	non-VR	23	1.00	.00	.00

**Q7 was removed from the RTO-A assessment at some point so we don't have responses to that question from everyone.*

Most people in each group could identify the correct tools (t = -1.78, p=0.83).

What 4 things should you do when operating the EWP? What to do before lowering EWP?

There were significant differences between the groups on these questions.

Table 12: Operating the EWP, immediate assessment – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Q8*	VR	39	3.09	.83	.14
	non-VR	22	4.00	.00	.00
Q9*	VR	42	.88	.29	.05
	non-VR	22	1.00	.00	.00

**Q8 and Q9 were removed from the RTO-A assessment at some point so we don't have responses to that question from everyone.*

Non-VR group listed significantly more steps than the VR group did (t=-6.82, p<.001), and gave a correct answer to what they should do before lowering EWP (t=-2, 68, p=.011).

Describing the steps to carry out work at heights safely.

These were evaluated based on the assessment checklists to operate the EWP. We did not run a comparison between VR and non-VR group for this question as it was a checklist for the Working at Heights assessment and everyone received satisfactory results. Instead, below, we report descriptive statistics for the VR group for each step.

Table 13: 7 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). See 7 steps in EWP operation for a reference.

Assessment of learning – One-month retention

Theory: 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 14: Hazard and elimination of hazards, one-month retention – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
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

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).

Theory: PPE

There were significant differences between the VR and non-VR group in relation to PPE.

Table 15: PPE, one-month retention– group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
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

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).

Theory: Fall prevention devices and harness inspection

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).

Table 16: Fall prevention devices and harness inspection, one-month retention – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
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

Where should all tools and equipment be when in the EWP basket?

Similar to the immediate test, we found no significant difference between the VR and non-VR group in relation to how they answered this question (t=-1.06, p=.296).

Table 17: Tools and equipment, one-month retention– group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Q7	VR	27	.83	.31	.06
	non-VR	15	.93	.26	.07

Both the VR group and the non-VR group were able to answer this question.

What 4 things should you do when operating the EWP? What to do before lowering EWP?

In contrast to the results from the assessment conducted immediately after training, we found no differences in how groups answered these two questions.

Table 18: Operating the EWP, one-month retention – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
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

The VR and non-VR groups gave similar number of correct steps to the Q8 (t=.39, p=.70), and Q9 (t=.78, p=.44).

Describing the steps to 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 19: 7 steps in EWP operation, one-month retention – group descriptive statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
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).

Interaction data

In order to determine what the participants did when they were in the VR training environment, two primary measures were extracted from the logfile data: time on task and interactions. These were calculated for the whole experience as well as for each stage outlined in the learning design: onboarding tutorial, identify and confirm etc, inspect the site, select and inspect etc, harness check, prepare and access the etc, work safely at heights, clean up. Not all of the logfiles were recorded, 50 log files were considered appropriate to include in this analysis.

Time on task

The amount of time that participants spent in the virtual environment ranged from 13:25 minutes to 50:30 minutes. The mean total time was 27 minutes 37 seconds.

Table 20: Descriptive statistics for time on task

VR stage	Minimum time	Maximum time	Mean time
Onboarding tutorial	0:02:49	0:22:16	0:05:27
Identify and confirm work requirement	0:00:14	0:02:21	0:00:29
Inspect the site	0:01:22	0:18:15	0:05:00
Select and inspect materials, tools and equipment	0:00:50	0:18:48	0:02:56
Harness check	0:00:00	0:05:40	0:01:34
Prepare and access the work area	0:00:00	0:07:16	0:01:07
Work safely at heights – select tools	0:00:00	0:03:51	0:01:34
Work safely at heights – check the EWP	0:00:00	0:02:55	0:01:13
Work safely at heights – operate the EWP	0:00:00	0:27:15	0:07:25
Clean up	0:00:00	0:01:35	0:00:21

As can be seen above, the mean time spent on the onboarding tutorial was approximately 5.5 minutes, with the minimum almost 3 minutes. Other than that, most of the participants' time was spent operating the EWP (7.5 minutes) and inspecting the site. Minimal time was spent cleaning up after the EWP operation was complete.

The time to reach the goal of changing the lightbulb was also recorded. Only 43 participants reached the goal, the quickest that a participant completed the task (after completing the tutorial) was 9:53 minutes, the longest was 26:21 minutes. The mean time to complete the task was 17:58 minutes.

Most participants progressed through the training in a linear approach, moving from one task to the next and not returning to previous workstations. A typical progress can be seen in Figure 18.

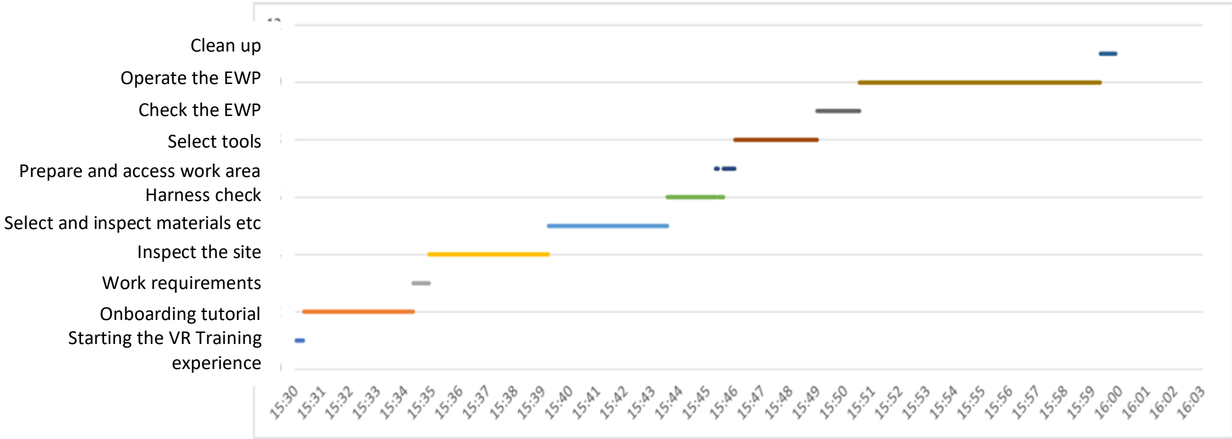

Figure 18: An example of the time spent on each stage

Interactions

Interactions in the virtual environment included both the selection of objects through clicking as well as by grabbing. The number of interactions that were recorded in the virtual environment ranged from 120 to 510 selections. The mean total number of interactions was 264.

Table 21: Descriptive statistics for number of interactions

VR stage	**Minimum number of interactions**	**Maximum number of interactions**	**Mean number of interactions**
Onboarding tutorial	29	159	52.65
Identify and confirm work requirement	2	14	5.10
Inspect the site	10	127	58.94
Select and inspect materials, tools and equipment	8	132	35.51
Harness check	0	38	20.39
Prepare and access the work area	0	75	10.06
Work safely at heights – select tools	0	41	13.10
Work safely at heights – check the EWP	0	35	11.10
Work safely at heights – operate the EWP	0	115	49.06
Clean up	0	20	3.47

As can be seen above, the mean number of interactions during the onboarding tutorial was approximately 53, with the minimum 29. Other than that, most of the participants' interactions occurred when inspecting the site (59) and selecting and inspecting materials and equipment (36) and when operating the EWP (49). Minimal interactions took place when identifying the work requirement and when cleaning up after the EWP operation was complete.

In order for participants to receive feedback on their progress through the training, some tasks included feedback in the form of green ticks or red crosses depending on their selection. The stages that included this feedback were the tutorial, inspect the site, select and inspect materials and equipment, the harness check, and the selection of tools for the EWP. Most students selected appropriate options and received positive feedback on their selections. There were minimal incorrect selections made.

Table 22: Descriptive statistics for number of correct and incorrect selections

VR stage	**Minimum number of interactions**	**Maximum number of interactions**	**Mean number of interactions**
Onboarding tutorial – valid selections	2	4	3.96
Onboarding tutorial – invalid selections	0	0	0
Inspect the site – valid selections	0	13	12.49
Inspect the site – invalid selections	0	4	0.49
Select and inspect materials, tools and equipment – valid selections	0	12	9.41
Select and inspect materials, tools and equipment – invalid selections	0	5	0.6
Harness check – valid selections	0	5	3.92
Harness check – invalid selections	0	0	0
Work safely at heights – select tools – valid selections	0	10	3.18
Work safely at heights – select tools – valid selections	0	0	0

Participants only selected incorrect options for inspect the site, select and inspect materials, tools and equipment. All other selections were correct.

Usability and User Experiences

Participants were asked to report on the different aspects of the VR training to measure the usability of the system on a 5-point Likert scale.

Table 23: Usability items were presented in a 5-point Likert scale (N=57)

	I could see the images clearly	I could read the text clearly	I could hear and understand the voice narrator	I could interact with the display in a straightforward way	I could move around easily
M	4.35	3.93	4.56	3.91	3.96
SD	.668	.904	.598	.830	1.017
SE	.088	.120	.079	.110	.135

They reported that audio-visual quality (could see images and read text clearly, and could hear the voice narrator) high, and that they could interact with the objects in the training. Overall, the system had high usability.

Simulator sickness

We asked participants to what extent they might have experienced simulator sickness during the VR training. The average was 2.09 (SD=.93) which means that they only had a slight discomfort overall. We further asked them to tell us about their simulator sickness, and the most common was slight dizziness, and slight nausea.

User Satisfaction of Experience Questionnaire

USEQ had six items, each on a 5-point Likert scale.

Table 24: Descriptive stats on the user satisfaction of experience questionnaire items (N=57)

	Did you enjoy your experience of the VR system?	Were you successful using the VR system?	Were you able to control the VR system?	Was the information provided by the VR system clear?	Did you feel discomfort during your experience with the VR system?	Did the VR system meet your expectations?
M	4.18	3.82	3.86	4.36	3.77	4.04
SD	.889	.974	.875	.724	1.086	.906
SE	.118	.130	.116	.097	.144	.120

On average, participants reported high levels of satisfaction with their VR experience (M=4.0; SD=.66). The averages for each item could be seen in the able below.

Enjoyment of the experience

Participants filled out a 7-item Intrinsic motivation inventory scale to measure their enjoyment of the training experience both immediately after the training and after one-month.

Table 25: Enjoyment results

	IMI Enjoyment (immediate)	IMI Enjoyment (one-month)
M	6.06	5.63
N	57	32
SD	.91	1.04

Participants stated that they enjoyed the experience very much, and they had a similar recall of their VR experience in the survey after one month(M=5.63, SD=1.04).

Participants rated how much they valued the VR training experience on a 7-point likert scale.

Table 26: descriptive stats of enjoyment scores (N=57)

	PENS Competence	PENS Autonomy	IMI Value
Mean	4.14	4.10	5.51
SD	.94	.81	1.39
SE	.13	.11	.18

On average, participants thought the experience was valuable for their learning (M=5.5, SD=1.39). They also rated their sense of autonomy and competence using the Player Experience of Need Satisfaction Scale (PENS) which were out of 5-point Likert scale. On average, they felt very competent and capable in the VR environment, and felt high levels of volution.

NASA Mental Load Scale

NASA Mental Load Scale was used to measure how participants felt the VR training mentally and physically demanding. The scale had six items.

Table 27: Descriptive stats NASA Mental Load Scale

	How mentally demanding was the task?	How physically demanding was the task?	How hurried or rushed was the pace of the task?	How successful were you in accomplishing what you were asked to do?	How hard did you have to work to accomplish your level of performance?	How insecure, discouraged, irritated, stressed, and annoyed were you?
Mean	43.44	15.59	13.63	78.23	32.98	16.79
N	52	46	43	56	50	43
SD	28.56	19.01	15.34	26.71	24.12	21.85
SE	3.96	2.80	2.34	3.57	3.41	3.33

The items are in a scale of 0-100 that can be adjusted with a slider. Overall, it seems participants thought the mental demand was slightly higher than any physical demand, and that they did not find it difficult to accomplish the tasks, and they thought quite successful to accomplish them. The breakdown of the item level averages can be seen above.

Sense of Realism

We measured participants sense of realism in the VR training using 4-items in the iGroup presence questionnaire. Participants found the training moderately realistic (M=4.02, SD=.51). There was a significant correlation between the reported videogame experience and sense of competence people had during the training (r = .35, p=.008).

Survey after one month

Participants were sent a survey one month after their training. After the initial email, two reminders were sent to the participants. Both groups were asked what they remembered from their training, what they remember enjoying and not enjoying. In addition, they filled out the IMI survey enjoyment scale, and answered the same ten questions on theory and practice. In total, 32 participants from the VR group and 21 participants from the control group responded to the survey.

Enjoyment

VR group remembered their VR training experience as slightly more enjoyable than the non-VR group did their in-person training experience (t=. 1.90, p = .063).

Table 28: Delay - enjoyment

Group	N	Mean	Std. Deviation	Std. Error Mean
VR	32	5.63	1.04	.18
non-VR	23	5.14	.83	.17

Short response analysis (VR group)

All short responses were analysed to determine common themes. In terms of what the participants remembered about the VR training experience. Many mentioned the general tasks that they engaged in during the training exercise (e.g., finding hazards, driving the EWP, fixing the light; n=8).

> *"the introduction, learning how to use the scissor lift, learning about the controls, learning about hazards in the path of the scissor lift"* (P159)

Even more prevalent were responses relating to engagement, realism, and immersion (n=9).

> *"It was fun getting in the EWP and genuinely feeling momentum moving the plant and coming to a stop. I'm pretty sure I almost fell over :)"* (P141)

> *"Working at heights. It felt realistic"* (P145)

Some participants remembered the training benefits that came from the VR training exercise, including it being cost efficient, being safe, and a good addition onto in-person training (n=4), and a small number recalled usability issues, including the experience of VR sickness (n=3).

When asked specifically what they remembered enjoying from the VR experience, a large number of participants spoke again about the design of the VR Training Research Environment – such as level of engagement, realism, and immersiveness they experience in the VR Training Research Environment (n=7), and the same training benefits as mentioned previously (however, more participants mentioned it here, n=9). Other aspects they enjoyed included it being a fun and interesting experience (n=6), the feedback they received throughout the training (n=1), the visuals (n=2), and the novelty of it (n=2).

Very specific aspects of usability were observed in response to what they remembered not enjoying about the VR training experience. Some of these are related to the design of the VR Training Research Environment, such as the general design (n=3), glitches (n=5), interacting with the controls (n=4), and the audio and general quality of the application (n=2). Interestingly, three participants noted issues with realism, whereby, in contrast to others, they felt the training experience was not real enough (n=3). Others were related to being in VR in general, such as not enjoying the feeling of not having a sense of presence in the real-world environment (n=2), or experiencing VR sickness and discomfort (n=9).

Short response analysis (non-VR group)

A total of 23 participants responded to the short response questions. They talked about remembering how to operate the scissor lift. They said the instructions were straightforward and quick, and the instructor was professional. A few listed learning about PPE, hazards, and how to complete safety inspections; and others specifically brought up the practical part of the training.

With respect to enjoyment of the training, most said they enjoyed the practical aspects of it. P253 also enjoyed experiencing different models.

> *“The most enjoyable aspect was operating the actual EWPs. In particular, the 2 models made by different manufacturers were very distinctive in the way they behaved and were controlled.”* (P253)

A few participants also said they enjoyed the teaching style of the friendly instructor who turned fairly dull topics into something interesting, “Trainer was engaging and turned fairly boring training into a pretty good day” (P257)

Lastly, they were asked if they remembered anything that they did not enjoy about the training. Most said they did not have anything that they did not enjoy. A few mentioned the some of the materials being old, “Some of the enactment movies were old” (P252)

Semi-structured interviews

Following the VR experience, the researchers conducted a short interview with the participants. Some participants had to leave for their training or job responsibilities. The interviews lasted between 4 to 10 minutes. In total, 48 participants were interviewed about their experiences. They were asked to compare the VR training experience with the previous training they have completed (if they had), about the feedback in the VR training, how it compared to the previous training, what they liked about the VR training, what they found challenging, and what they would change.

The interviews were recorded and transcribed initially using Otter.ai. They were then reviewed for accuracy by the research team. The transcribed interviews were imported in the qualitative analysis software NVivo and analysed using thematic analysis.

Comparison with current training

Participants were asked how their experiences with the VR training compares to their previous experiences with working at heights and EWP training.

Some indicated that the VR training was a comparable representation of the physical training. A few highlighted that "aside from the swaying" (P154), driving the EWP sufficiently matched their real-life experience. Others mentioned tasks such as identifying hazards and checking the logbooks. 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 where they drove a meter forward, up, backwards to show their competence.

> *"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)

A few participants identified the structured approach to learning in the VR group, "…[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)

P117, insisted that there were absolutely no similarities between the two types of training, listing physicality as well as the linear structure of the 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... the robot lady basically talks to you as if you don't know anything. 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, "it 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)

Several participants compared the intensity of two training applications. 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)

Feedback and Instructions

Most participants collated feedback and instructions they received from the system (e.g., what the disembodied agent told them to do compared to the feedback they received when they completed the task) and concluded that that the system provided clear and straightforward instructions and feedback (n=36). They did not get lost, and if they had difficulties with the VR system, the researchers helped them out. They found feedback relating to task completion to be clear, i.e. receiving a green tick to indicate a correct action. Below is a representative quote from a participant.

> *"I think it was pretty clear if you had done something right or wrong, or if something was still left to do, with the little blue arrow. Yeah, I thought it was perfect with the green tick, or whatever."* (P158)

Some indicated that the instructions and feedback in the VR training were comparable to feedback provided in the physical training (n=9), where the system indicates what was done wrong, as did the in-person trainer.

> *"I think it [the feedback] was pretty close [to their previous WH training]. So, everything was relevant."* (P113)

> *"It was the same. Exactly the same instructions"* (P138)

Participants felt the lack of personalised feedback that would be provided by a trainer in the physical training. One participant said the feedback was not specific enough "*Yeah, I guess physical training is a bit more personal. Feedback specific to what you're doing.*" (P120) The same participant talked about how, sometimes in the VR environment, the system would not register or give feedback on what he was doing wrong when he could not pick up an object. Similarly, another participant indicated that she was not sure what she missed in the process when she could not proceed to the next task, "*Well she says that I completed, but I will ... probably, I will add something that I say, 'you are missing this' to move to the next step. Like giving you, what is the error?"* While our research assistants helped in situations like this, there were some cases the precise cause of the error was unclear or difficult to discern.

In relation to the trainer, some brought up that they valued the insights that experienced trainers could provide in the physical training. For example, P114 said,

> *"The only thing is the difference between working with someone who's had real life experiences and just knows the different nuances about it. It can change things. Just personal experiences. Really. That's about it."*

Two participants (P108, P154) said they were trying to get used to the controls and the virtual environment, so they missed the guidance from the system. This luckily did not affect their successful completion of the training. The VR system had used a synthetic voice rather than a human voice to provide instructions and guidance to the participants. P112 and P159 expressed preference for an actual human voice, "the voice itself was robotic. I would probably change that" said P159. P112 provided a reason for his dislike, "*it was sort of hard to focus on the voice of the lady, because I think* *it was just that sort of like, robot-y sort of voice…if it felt like if it was a real person talking to me, I'd be more onto it and alert."*

Some others highlighted that the feedback from the environment (such as wind, motion, and touch) received during the VR training was different from the current training.

> *"It was probably obviously more realistic [referring to the physical senses] in real life. The feedback was more verbal, but it was also visual and like, there was a lot more to work with in real life. And then in VR, it was still good. It just didn't give me as much information to go off with that sort of stuff."* (P112)

What was good about the VR training?

We asked participants if they liked anything in particular about the VR training. They talked about various aspects of the VR training and how some of the design aspects made them feel.

Safe and supportive learning environment

The design of the VR allows for safe exploration of different scenarios in a controlled environment without a risk of falling off, damaging equipment or other people. Participants found it as a good training exercise (n=13). Thanks to the immersive nature, while they might still feel afraid of heights in the VR, they would not have an accident of falling off the EWP in the virtual environment. As explained earlier the safe environment seem to lead to less stressful experiences. 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 brought up that they found it less stressful as they went through the training by without a classroom full of people who would observe them.

Participants (n=17) commented how proceeded in the VR training at their own pace and from their own perspective, and with more control on 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."*

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 "because you can just experience it yourself" (150)

Related to agency, participants talked about how they enjoyed the interactivity in the VR environment. P114 thought the VR training experience resembled a game giving him freedom and choice to "operate it like a game in a way and move around, flick around and 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… "*

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…"

As a result of interactivity, individual experience and sense of control, participants talked about paying more attention and concentrating on the training. It was also brought up that during the face-to-face training trainees can get distracted or the lesson could go off the course caused by others asking questions or interrupting. In a relevant note, P144 brought up that doing the same training multiple times can cause them paying 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)

Learning Design

Several people brought up how the VR training was a lot more standardized and structured compared to the in-person training. They saw a value of actually completing a set of tasks and assessing their worksheets and different items towards a goal in the scenario as it seems they don't get a chance to do it in face-to-face training as it is usually very fast paced and in a classroom environment.

> "I guess it's a set out. There's everything. Everything's in there that you need. Sometimes I guess, in real life, teachers can fall short with human error and that sort of thing. And you could walk away with something less than the guy before." (P120)

Some also mentioned that the VR training was scaffolded enough that by the time they reached the EWP they would learn most of the relevant controls for the training.

Novelty and fun

Several participants remarked that they found the VR training fun (n=10). Some said the VR training was different to the same in-person training they had done multiple times. A few also mentioned it being faster than the traditional training, "it was faster, it was something different… it's new."

Overall, a few participants (n=3) specifically commented that they would do VR training in the future. Some (n=5) remarked that VR training would be a good experience for people to prepare them for the actual training to learn the procedures. Many (n=13) highlighted that VR training would be a great for beginners, "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 tonne machine and possibly hurt yourself, like I think, I think that's great" (P105).

Fidelity of the visualisation and authenticity of the training experience

Many (N=15) found the training to be an authentic simulation of what someone might expect from working at heights training and learning to drive an EWP. They concluded that overall "*it was a good training exercise.*" (P131) This participant thought that the VR training gave him an idea of what he could do in the training, and many others indicated that it felt real, "…even though it is simulated…" (P107)

> *"It did have sort of like, a realistic obviously, it wasn't as realistic as life is, but it sort of gave you that feeling of a workshop, you know, I guess if you've never been in a workshop before. Being in that sort of situation in VR was very what's the word..."* (P112)

One of the participants said the VR training gave him a lot more experience than the in-person one,

> *"it's just valuable… it felt pretty real controls… I thought that was good because you had to do a little bit more… The real one I did was, you went through all the safety stuff, then you went into a scissor, turned it on, went up one metre, came back down, moved it forward a metre, turned it off, that was it. Then gave you your ticket and sent me on your way."* (P158)

Some others emphasised how interactions were high fidelity. *"The scissor lift seemed to be pretty realistic… the operations, paperwork, controls… looked exactly the same*" (P136) In the same line P145 said driving the EWP was "*pretty exactly like driving a normal [real] one*."

Relatedly some talked about representation of the environment – e.g., display being high fidelity. In relation to these, many participants suggested that VR training might be a good starting place for novices and those who might have a fear of heights to introduce them to the training scenarios.

The display quality and audio of the VR system immersed participants in the training. Participants (n=6) talked about how they did feel that they were in a workshop and that the driving sensation was comparable to operating the EWP in real world. Some referred to their experience as very engaging and feeling very real and that they forgot that room they were in. In addition, they talked about how they expected certain things to happen, referring to plausibility illusion in the virtual world.

> *"It feels so real, very real. Like you can like crush with something and you can feel it like when driving it."* (P138)

> *"… in the virtuality it still gives the same sensation of going around, like, as soon as you stop going around the corner, you felt like you're gonna fall off, because you had nothing to hold on to. So your brain just plays mind games on ya "* (P131)

Some also talked about the sense of place, and how the completeness of the virtual world surprised them:

> *"Walking out to the garage door and seeing what appeared to be an actual world out there. That surprised me. Because I mean, you think of a photograph to be used as a backdrop and you don't think it's ever going to translate to something that looks remotely real. But, I guess because you're cut off there and you can't walk out there, it's like, yep, it looks real enough. You can't go out there to check so, that'll do. So that was pretty impressive."* (P141)

Challenges with the VR training

We asked participants whether they experienced any challenges during the VR training, and whether they found some aspects of the training not comparable to the in-person training.

No actual trainer

Five participants emphasized that lack of a trainer was a drawback. They talked about missing out on being able to ask questions to trainers and learn from their experiences.

Difficulty and unfamiliarity with VR

There was a slight barrier to entry when it came to using the VR equipment (n=18) and that barrier shaped some participants' attitudes towards the experience. Many indicated that they struggled with the VR equipment and controls (n=14). Some experienced discomfort with the headsets, "*make it more accommodating for the straps because it made it difficult to see because it wasn't sitting on my head correctly*." (P125) Regarding the use of the other controls, overall, the users described a brief learning curve that they had.

> *"[The controls] are a bit confusing […] once I kind of got the hang of it, it wasn't too bad. But it was, yeah, a little bit sensitive."* (P125)

> *"I think it was just hard to, to pick up the VR..."* (P121)

While many had enjoyed the novelty of the experience, some admitted that it was also was a challenge, "*That was a bit tricky, because I was blown away with how it worked, because I've never done any VR stuff before.*" (P134) This was sometimes attributed to a lack of experience with computers and videogames, broadly.

Most were confident that with some more practice they would get good at using the controls, and overall, the tasks got easier as they learned the controls throughout the VR training, "*it got easier once you know which buttons to press...because I've never use that in my life before*" (P147).

Motion sickness and Glitches

Difficulties with teleportation and movement of the EWP led some participants to experience disorientation or motion sickness. Five participants specifically brought up feeling dizzy or disoriented due to movement in VR, "As soon as I moved, I was like, woah." (P149). For most, this was not severe, "*I got a little bit dizzy at times in VR but nothing like where I'd have to stop*." (P136)

A few also brought up glitches they experienced during the VR training which might have contributed to feeling disoriented such as lag feeling (P109), jittery graphics (P105) and clipping through the objects (P110, P112).

> *"… it's really good that you got that reset button for everything to go back, but like with my body being halfway through the table, like my brain just couldn't comprehend that."* (P110)

Moving around in the VR environment

Being able to move around in the VR environment via teleporting was one of the most challenging actions for some people (n=9) as most could not gauge the virtual distance and ended up teleporting sometimes too close to the objects like tables and displays which contributed to people's feeling frustrated, disoriented and dizzy. Below are representative quotes from the participants:

> *"I clicked the joystick and that, and next thing I'll be somewhere else.. yeah, I'd flick around and then I'll be at a wall"* (P144)
>
> *"I kept … transport[ing] myself. I didn't know where I was. And then I kept getting my head in the table or something."* (P158).

P133 thought that because he could move around better in the physical world, he would prefer the face-to-face training for now, "*Only because you can manoeuvre yourself a lot easier. I think if you're able to be able to fix that part, it would be as good*." (P133)

Interaction design and the immersive environment

Some of the interactions such as difficulty of picking up objects in the environment were found to be inhibiting to the users' progression (n=7). In some cases, this was attributed to the difficulty of the required controls to carry out the task. P102 and P104 retold the interviewer that they had difficulty grabbing the control/driving stick of the EWP as the selection box was very small, "*I couldn't quite interact with the control stick to move it or lift it.*" (P102)

Some participants (n=7) had difficulties reading documents in the VR scenario. A few phases of the training required people to read through short cards (e.g., different types of hazards, a list of PPE to put on). All described writing as blurry and difficult to read. Some said it might be because they were not wearing their glasses, others found that moving the HMD improved it.

Lack of physical interactions, sensations and feedback

Many people (n=13) brought up lack of physical sensations, interaction, and feedback that they were used to having in the face-to-face training as a disadvantage of VR training compared to face-to-face training. P106 and P109 specifically wanted to be able to interact with the virtual objects using their own hands, and others gave examples of how they would get feedback from the real world, including the sense of being up in high, feeling the wind and the machine swaying.

> *"You just don't get the real life feeling of actually taking something up in the air and being up in the air."* (P113)

Specifically, P108 and P148 talked about they were looking for the feedback they would get when they were bracing to move, "*you're sort of used to like when you're using an EWP like to lean for like, the balance of like the movement…"* (P148). In the same vein, P142 explained,

"…normally when you're operating a scissor lift, you're holding on to something, whereas you can't hold on. So when the machine stops, yeah, like, I actually took a step forward when I let the accelerator off too quickly, because I'm so used to happen in a real life. Yeah. But apart from that, it was, you had still the same sensation of being on the platform going up and down was a similar sensation." (P142)

Future Design Opportunities

As the final question in the interview, participants were asked what they would change with the VR training to make it more effective for them.

Scissor Lift modifications

Participants wanted a more realistic experience of the EWP training and some gave input on the realism of the scissor lift operation.

One of the main points of feedback was regarding the lack of feeling of sway, induced when the scissor lift is high above the ground. This was remarked as important physical feedback as it contributes to the negative vertigo sensation that must be overcome to do working at heights.

"*I'd say, just put that slight sway in, especially when it starts going higher. It will give it a lot more realistic... to throw people off, instead of just the mindset of like, I can just go up. Put that sway in will increase the real effect of it."* (P131)

Participants pointed out some inconsistencies regarding their personal experiences with scissor lifts and the one provided in the VR training. They suggested that this could be an opportunity for introducing different models of scissor lifts in order to increase the variety of the training. A few participants noted that the scissor lift interactions could be more detailed.

Interaction design

The movement throughout the environment was mentioned by some users. They described the teleporting as too instantaneous and difficult to control the endpoint. This resulted in getting lost or stuck in objects. This might be prevented by allowing users to teleport to certain points in the environment as suggested by a participant

"I'd want to go to a certain spot, and felt like there was that blue arrow that sort of launched you in that direction. […] So it needed more constraints around how you could move." (P112)

Another user described the collisions between objects as something they would change as it was immersion breaking.

Learning design

Some participants discussed suggestions on different tasks that they felt deserved more attention. This included expanded instruction on how to put on a harnesses and related PPE, environmental hazards such as wind and uneven ground, and a more realistic working-at-heights task. One user suggested that this training task would be suitable for beginner users only, given that on its own, this training is too simple for certification.

"If this was a test, it'd be a pretty easy test. And then a lot of people get the licence, you know. […] It kind of feels like that there needs to be a degree... degrees of like, beginner, intermediate, and expert." (P154)

A few users discussed the potential for VR to introduce hazards that are not possible in the real training environment.

Hardware and the learning environment

Some users complained about the hardware limitations, suggesting that they would change having to wear a headset, or have special gloves to make interactions feel more real. One user commented that they couldn't wear their glasses with the headset and thus couldn't read the required documentation.

A few participants complained about the lack of physical space provided for the VR training, as they hit the wall or a table. Others just wanted to be able to walk a bit more naturally and felt hindered by the cord linked to the headset.

> *"I'm not used to VR, so that was a different sort of thing for me. But like, it's hard to try and keep a focus on whether, you know, like, how much surroundings you've got in real life compared to the actual VR. So maybe a bit more space."* (P112)
>
> *"Probably start me in the middle of the room so I'm nowhere near a table."* (P135)

Discussion

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?* Based on the review of the literature and consultation with stakeholders, we divided the questions into those related to research about learning for competency and design of VR for training. Four areas were identified that were of interest to research about the effectiveness of the VR environment for learning: opportunities for learners to exercise agency; the physical location in the virtual environment (such as quality of visuals, size, stations); the immersiveness of the virtual environment; recall after one month. The areas related to the design of VR for training were: reliability of the technology for mass utilisation; and the provision of feedback in virtual environments. Drawing on the reported results, we have organised this discussion in terms of learning outcomes, learning and pedagogical design, and the digital and physical learning environment.

Learning outcomes

Two assessment measures were used to determine the learning outcomes: the theory items and a description of the steps involved. In terms of the theory items from the assessment, there was no significant difference between the VR group and the non-VR group for most items when the questions were answered immediately following training. The non-VR group scored higher than the VR group in describing the compliance checking of the EWP. After a delay of one month, there were few differences between the VR and non-VR groups. Participants in the non-VR group were able to better define PPE, however users from both groups were able to give appropriate examples.

With respect to the description of the steps involved, immediately after training, participants in the VR group were unable to describe the steps after the goal of changing the lightbulb was reached. These included parking and shutting down the EWP, securing outriggers, carrying out post-operational checks and completing any housekeeping procedures after operations. After a one-month delay, those in the non-VR group scored higher in their description of the selection of tools and equipment and also the set-up of the EWP than the VR group. Participants in the VR group were able to better describe the housekeeping procedures. There was no significant difference reported between the groups in the scores achieved for reporting the other steps.

With respect to learning outcomes, the VR group performed similarly to the non-VR group in most assessment items. These results support the finding that this VR training environment was effective for a unit of competency when compared to traditional training. To explain this finding, the following sections will explore the learning and pedagogical design and the digital and physical learning environment.

Learning and pedagogical design

There were several elements of the learning and pedagogical design that supported learners when engaging in the VR environment. These were directly related to the principles outlined in the VR Training Design Framework: participants must understand how to use the tools available to them (this will be discussed in the section about the digital and physical learning environment); participants should be encouraged to adopt a role/persona in the VR environment; all participants should be presented with a consistent training experience with clear steps to follow; participants should be allowed to repeat a task until they can demonstrate that they can complete it correctly; participants should be given multiple opportunities to demonstrate their understanding; participants should have the opportunity to connect theory and practice in an authentic and safe environment.

Adopting a role/persona in the VR environment: Agency

The design of the VR environment provided many different opportunities for users to exercise agency, mainly through the interactive features. In traditional approaches to this training, learners sit in a classroom, listen to lectures, watch videos, are shown what to do in the warehouse and then asked to demonstrate it. The virtual learning environment provided ways of interacting with the equipment that resembled a game. Even just observing in the virtual environment was noted as being different to watching a video. This is because they have a role within the environment. They had agency over their learning. The VR environment also gave users an opportunity to explore and try things for themselves, rather than be told. In the interviews, users described how this agency meant that they paid more attention and concentrated on the training that they would in the traditional training setting. Many of the participants commented on how they could proceed with the VR training at their own pace and from their own perspective, with more control. They could pause and have time to think before acting and move through at their own pace instead of going as quickly as everyone else.

All participants should be presented with a consistent training experience with clear steps to follow

Approximately 50 participants completed the VR training environment. The environment was designed to support agency while ensuring that each user had the opportunity to learn the required material. In the interviews, participants identified the structured training as a positive thing, and appreciated not worrying about whether the teacher was delivering the same experience for everyone. Instructions were provided in multiple forms – through a female, electronic voice as well as the written instructions available on a tablet attached to the user's virtual hip. Of the 43 participants who reached the goal of changing the lightbulb, the longest amount of time taken was 26 minutes, 21 seconds. Participants had different views about the instructions while most considered them straightforward – one describing the steps as simple.

Participants should be allowed to repeat a task until they can demonstrate that they can complete it correctly

The VR environment was designed to be structured with a clear process and scaffolded with respect to completion of each task. Location was used within the VR environment with different workstations representing each stage. None of the users returned to previous workstations unless they accidentally teleported before completing a task.

The design of the virtual learning environment included feedback to the user for some of the stages in which they were asked to make selections or position signs appropriately. The interaction data showed that all users selected only correct options in the tutorial, the harness check, and the tool selection. Some incorrect options were selected when inspecting the site and when selecting and inspecting materials, tools and equipment. The interviews showed that most of the participants reported that the system provided clear instructions and feedback.

For some of the participants, it matters who it is that they are demonstrating their learning to. They commented on requiring feedback that was personalised for them. Some also indicated that the experience of a real person was more valuable than a computerised voice. Some reported that there were system errors and there was not feedback for all interactions. Thus, while most indicated that they had a good idea when they got it correct, they had doubts on what to do when they could not proceed. In these cases, the research assistants aided the users. However, without a person there, the participants were identifying for themselves when something was correct or incorrect. While most indicated that they had a good idea when they got it correct, they had doubts on what to do when they could not proceed.

Participants should be given multiple opportunities to demonstrate their understanding

The design of the virtual learning environment was done so that the experiences were scaffolded and built on each other. In the classroom training environment, learners are able to repeat processes until they have demonstrated the required standard of competency in the particular skill. The design of the VR training research environment included options to demonstrate skills (such as the identification of hazards) that included multiple options for selection. The VR training research environment 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 taking time before demonstrating a particular skill.

Participants should have the opportunity to connect theory and practice in an authentic and safe environment

Safe and supportive learning environment – interviewers said pressure could be high in current training environments with risks to learners and equipment, while the learning is viewed as individual by the stakeholders and observed by classmates. Time is also seen as a pressure in the current learning situation that wasn't seen as a pressure in VR. Participants viewed the VR training experience as a personal learning experience, and they trusted that they had received experience consistent with others. Enjoyment scores were high indicating that participants enjoyed the VR training akin to a videogame experience.

In addition, they also were able to make mistakes without risk of damaging equipment or injuring themselves or other classmates.

Digital and physical learning environment

The discussion of the digital and physical learning environment will be organised around: visualisation and interaction design for engagement; and hardware and the physical environment.

Visualisation and interaction design for engagement

The VR training environment was reported to have provided high quality visualisation and interactivity. Analysis of the usability items showed that audio-visual quality (could see images and read text clearly, and could hear the voice narrator) was high, and that they could interact with the objects in the training. The user satisfaction of experience questionnaire showed that the information provided by the system was clear. The iGroup presence questionnaire showed that participants found the training moderately realistic, matching with their real-world experiences. The analysis of the interviews demonstrates that the fidelity of the VR training environment was high enough for participants to forget they were in the training room, referring to plausibility illusion in the virtual world with respect to driving the EWP. They also commented on being impressed with the completeness of the virtual world. The participants reported that the high quality of the VR environment was motivating and engaging for students to remain focused on the tasks.

One of the principles that informed the design of the VR environment was: participants must understand how to use the tools available to them. This was realised by the development of the onboarding tutorial. Interaction data from log files showed that the mean amount of time that participants spent on the tutorial was approximately 5.5 minutes. None of the participants made incorrect selections during the tutorial. Data from the interviews showed that the timing of some elements of the tutorial needs to be adjusted – that students were learning to look around, interact and listen to the voice-based guidance. However, this did not impact their ability to successfully complete the tutorial.

Some of the interactive features were described as initially challenging by participants, although most agreed that by the time they were in the final stages of the training (driving the EWP) they could move and make selections without significant issues. The main approach to movement (which was key to the learning design and questions regarding immersion) was teleporting. The decision was made due to the limited space available in the physical environment and also the decision to use a tethered headset (to support high quality visualisations). A small number of students reported that teleporting impacted on their feelings of dizziness or disorientation. In terms of interacting directly with objects in the virtual environment, some participants mentioned the challenges specifically in relation to driving the EWP.

The EWP received the most feedback in terms of replicating a real-world experience. Most of the comments about this are not directly related to the intended learning outcomes of the training and were not raised as important during the initial workshops. These included having additional examples of EWPs as well as the role of environmental influences on the experience of working at heights. Environmental influences include the swaying of the vehicle, feeling of wind, the use of hands-on controls (rather than the controllers), more accurate connection between the EWP controllers and wheel operation.

Hardware and the physical environment for VR

In the design of the VR training environment, decisions were made concerning the headsets, computers and available physical environment. A key element to be considered was the choice between a wireless or tethered headset. While wireless headsets are generally more comfortable for participants, fewer trip hazards, and have a clear impact on the opportunities for learners to engage in tasks that support the generation of knowledge through embodied cognition (by being able to walk around in the physical environment), they unfortunately have lower quality in terms of performance, reliability and set-up time. Given the evidence to support the impact of high-quality and high-fidelity visualisation on learning outcomes, need for mass utilisation, and the available physical space at the RTOs, the decision was made to use tethered headsets with powerful computers.

The usability questionnaires showed that most participants indicated that they could move around easily in the VR training environment. The interviews revealed that some participants experienced challenges in wearing the headsets – such as the straps not fitting properly or not being able to wear glasses. Some also found that they were bumping into objects in the physical environment (such as tables) and felt hindered by the cord that was linked to the headset. In those cases, research assistants redirected the participants to a safe location to continue their VR experience.

Overall, the technology can be considered to be reliable – approximately 59 people used the VR training environment and 41 reached the final goal of completing the entire training. There were initial challenges to running the VR training environment that were overcome. The different types of laptops were used at different RTOs and this had no significant influence on the outcomes in terms of learning or usability. Most challenges were able to be solved through general troubleshooting.

Limitations and future research

In this section we discuss the limitations of the research and identify areas of future research.

Learning

This research supports the claims that, for the learning outcomes for which the VR training environment was designed, the training was as effective as traditional approaches to training. This research indicates that, by following the recommendations outlined in the Checklist, VR could be used to supplement current competency-based training approaches, like face-to-face delivery. Although more research is needed, these results could be used to make substantial contributions to evidence-based policy discussions about the utility of using new technologies to deliver competency-based training in Australia, especially in high-risk industries such as construction. Further research could also investigate the amount of time needed in both physical and VR EWP training to identify the ideal amount of time needed to ensure learning outcomes are achieved.

This research identified feedback as an important element of the learning experience for participants, however this was limited to a simple display of correct or incorrect selections. Further research could investigate the impact of personalised feedback in relation to intended learning outcomes that captures information such as the order in which selections are made or advice for repeating an action to enhance performance. Additional research could investigate the role of the computer agent as a trainer and an actual trainer in terms of engagement, trust, and application of learning after training has been completed.

Digital and physical learning environment

As discussed above, the relationships between headset, physical environment and quality of the visualisation are likely to have an impact on learning outcomes, usability and enjoyment of the learning experience. Areas of future research include investigating the role of additional hardware, such as haptic gloves and physical props to approximate the key elements in the environment.

Note that limitations of space influence interactive feature design and navigation in immersive environments. These decisions, in turn, influence the design of interaction and movement within the VR training environment. Future research could explore the impact of these decisions on learning outcomes, usability and enjoyment. This could include the impact of removing teleporting and allowing free-roam or redirected walking techniques.

Checklist for the inclusion of VR in construction skills training

The results indicated that VR can be as effective as current approaches to training for specific learning outcomes. The effectiveness of VR is directly related to core elements of the learning design as well as the design of the training environment. If VR was to be implemented, we recommend that the following be used to determine whether the VR is suitable for use in construction skills training:

Learning Design Checklist:

1. Is there a trainer available to support learning? [instructor/expert as agents or humans]
2. Are the visualisations high enough quality to motivate and engage students? [visual fidelity]
3. Are the principles of compliance training adopted? [backward design]
4. Is the task structure clear? [structure and scaffolding]
5. Are there significant opportunities for learners to interact with the virtual environment in a similar way to the physical environment? [interaction fidelity]
6. How is feedback provided to the learners? [multimodal feedback]

Learning Environment Checklist:

1. Is there a staff member available to support technology implementation?
2. Is there an appropriate onboarding process within the VR environment?
3. Is there adequate space at the RTO?
4. What is the quality of the available headsets and supporting computers?
5. Will the performance of the available hardware support the visual quality in the training system?
6. Does the available hardware support learners to interact in a safe and supportive learning environment?

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