Final Report

AUSTRALIAN MEAT PROCESSOR CORPORATION

Mixed Reality Technology Training Pilot

Pilot Program – Comparison between conventional training methods and Mixed Reality Technology methods for Maintenance Departments to improve safety – Stage 1

Project Code
2021-1024

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1.0 Executive Summary

The Mixed Reality (MR) Training Technology Pilot Project sought to identify new mechanisms to support continued capability of the JBS maintenance department in supporting business operations.

The project set out to determine the efficacy of immersive reality (XR) technology in delivering technical training to operators, enabling just-in-time training and decreasing dependency on subject matter experts (SMEs). The planned program of work incorporated the following activities:

- Investigation of available technologies and determination of suitable vendors
- Identification of a pilot site and five tasks to be the subject of training
- Development of immersive reality training environment
- Overlay of critical task information, safe work method statements (SWMS), workplace health and safety (WHS) information, quality assurance (QA) information and relevant checklists onto training environment
- Implementation and evaluation of training program

Five tasks undertaken in the engine room at the Brooklyn meat processing plant in Melbourne were identified for the pilot. The review of available technologies identified augmented reality (AR) as the most promising technology to be used for pilot purposes and The Design Technology Company (DTCo) was selected as a vendor due to their strong industrial background and a focus on mechanical 3D modelling and drafting in industrial plants.

During the project, it became evident there were considerable limitations with AR technology and it was determined that a combination of AR and VR technology would be more effective. AR was identified as being effective in supporting detailed tasks, whereas VR provided more potential as an overarching training tool. Subsequently, the project scope was modified to incorporate VR technology in addition to AR for training purposes.

A Matterport Scan was completed to form the foundation of the MR training environment, creating a “digital twin” of the Brooklyn engine room, and an AR experience was created, aligning augmentations with real environment (for fixed objects such as machinery). The scan was also used to create a completely virtual model of the engine room.

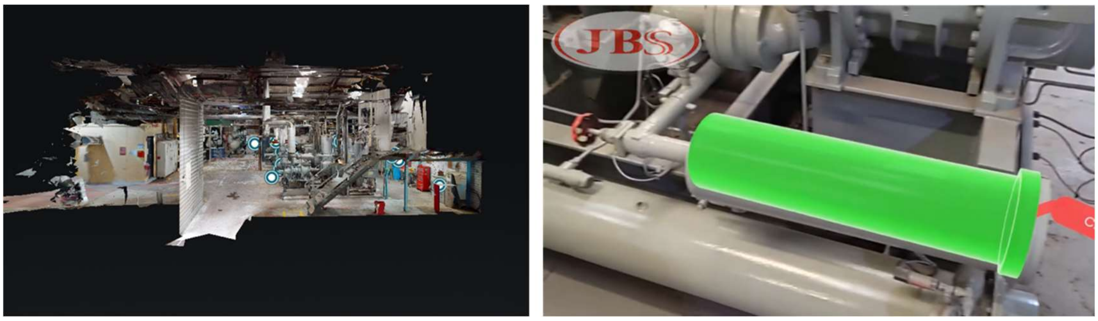


Figure 1 - Matterport Scan and AR environment

Figure 2 - VR Environment

Evaluation of the developed AR and VR training programs was directly impacted by travel restrictions as a result of the COVID pandemic. Following prolonged delays, an alternative approach to completing the project was negotiated in consultation with AMPC.

The alternative approach incorporated documentation of project team and JBS team member anecdotal reactions to the created training environments, as well as learnings and observations and the conduct of a literature review on mixed reality technology in training.

A summary of key findings and associated recommendations are captured in the table below.

Finding	Overview	Recommendation
Powerful technology	MR technologies present significant potential to improve organisational learning outcomes and deliver training in scenarios that would otherwise be inaccessible.	The industry and its individual organisations need to consider not if, but when and how they will integrate mixed reality training technologies into their learning and development offerings.
Considered use	The potential benefits of MR to improve learning outcomes are only likely to be realised with considered use of technology. The focus of training must remain on the desired learning outcomes and not be distracted by novelty approaches that could, if not used appropriately, result in expensive programs that deliver minimum benefit.	It is recommended that AMPC consider commissioning the development of “guidelines”, building on the findings of this project, to assist its members in determining appropriate use and considerations in engaging MR technology for training purposes.
Industry growth and maturity	Whilst the MR technology industry is relatively immature with regards to application in a training context, it continues to expand at a rapid rate, making it difficult to stay abreast of the latest developments and application. Organisations need to tread carefully and seek assistance from trusted professionals to help navigate this complex and ever-changing environment.	It is recommended that individual organisations within the red meat industry ensure they have access to sufficient technical expertise when pursuing MR technology for training. It is also recommended that AMPC consider sourcing and appointing a “panel” of professionals that across the various areas of expertise required for MR training (e.g. developers, instructional designers, platform providers) and make the details of this panel available to its members.
Internal collaboration	MR technology is a cost-effective training mechanism if delivered at scale. To maximise cost-effectiveness, organisations should look to adopt an internally collaborative approach that incorporates key stakeholders such as the training department, IT department, procurement and other stakeholders,	It is recommended that organisations take an internally collaborative approach to adopting MR technology to enable realisation of cost benefits.
Foundational frameworks	This project has found there is a significant lack of foundational frameworks to guide the development of training materials for use in a MR environment. Such frameworks are required to guide effective development and utilisation of available technologies, ensuring design is focused on learning outcomes and not dominated by the technology itself.	It is recommended that AMPC consider commissioning the design of “guidelines” to provide the foundational tools necessary to guide effective instructional design and evaluation of MR technology training materials.

Finding	Overview	Recommendation
Procedural significance	Any training program is only as good as the content it is designed to deliver. The significance of clear and accurate procedures on which training materials can be based has been a key learning of this project - if procedures are not fully accepted by learning participants, it severely distracts from the overall training experience.	It is recommended that organisations focus on clarity of work procedures prior to commencing development of MR technology-based training. In addition, it's recommended that consideration be given to the degree of procedural information required.
New skills sets	With the anticipated uptake of MR technology training in a workplace context, organisations need new skills, or at least access to new skills, to design and deliver required content.	It is recommended that AMPC commission a program of work that identifies skills requirements for organisations to effectively deliver MR technology training. It is also recommended that this program of work be reviewed and updated on an annual basis for the foreseeable future

2.0 Introduction

2.1 Purpose

JBS Australia is embarking on an innovation program that will take a “whole of supply chain” approach across the business to drive performance, capture increased margins and create more value for customers and consumers. The Mixed Reality (MR) Technology Training Pilot was part of this program, seeking to provide new mechanisms to ensure continued capability of the maintenance department in supporting business operations.

2.2 Background

JBS Australia has a vast maintenance department with resources located at all facilities. Many employees hold trade qualifications including plumbers, Engine Drivers, Electricians and Fitters, and Turners.

It was identified that maintenance teams in JBS Australia face a number of complexities in ensuring team members are competent in undertaking required tasks, including:

- Team members undertake a vast range of duties within a dynamic workload. Some work is routine whilst other tasks are ad-hoc or have infrequent scheduling. There are challenges in ensuring team members are capable of undertaking ad-hoc or infrequent tasks in the absence of just in time training and/ or immediate access to instructional resources.
- Risk mitigation activities are not necessarily always undertaken (e.g. not checking for falling objects in the work area) or there is minimal evidence to prove they are being carried out.
- Risk mitigation activities are currently documented in long, cumbersome documents, reducing utilisation of these resources by team members and/ or contract staff.
- Instructions for tasks are not easily accessible at the time the task is being conducted, with many tasks infrequent or not undertaken until many moths after traditional training has been completed.
- Maintenance teams are being impacted by the rapid and ongoing introduction of new equipment in response to factors such as customer expectations, environmental management and animal welfare. Subsequently maintenance teams are increasingly required to undertake tasks that would have been covered in their formal trade qualifications.
- Due to labour market shortages, JBS Australia is also facing challenges in attracting and retaining maintenance engineers with appropriate qualifications.

These challenges are not unique to JBS Australia. They are faced by companies across the red meat industry and other protein manufacturing industries such as pork and chicken. The OHS Act (2011) requires companies to provide any information, training, instruction or supervision that is necessary to protect all persons from risks to their health and safety arising from work carried out.

The MR Technology Training Pilot sought to assess the benefits of alternative training platforms such as Augmented Reality (AR) from conventional training methods currently in use at JBS Australia (paper-based and e-learning) in the maintenance department. The intention was for this to be achieved through development and trialling of a Mixed Reality Technology Training Pilot Program focused on risk mitigation activities.

If successful, it was anticipated that the use of Mixed Reality Technology for training purposes would overcome some of these challenges by providing detailed instructions for maintenance staff at the right place, at the right time.

2.3 Scope

To enable an informed evaluation of the use of technology in training, it was determined to trial these technologies in JBS Australia through a narrow scope focusing on five tasks undertaken by a JBS maintenance department in an identified meat processing plant.

2.4 Previous research

Initial research indicated the development of technologies such as wearable computing, AR, and the Internet of Things (IoT) were providing more effective and less expensive training solutions and at the same time ensuring safety obligations are met.

Further, systems could be designed using MR technology to produce new environments and visualizations, where physical and digital objects co-exist and interact in real-time. AR was providing vision-based systems that enhance visual perception of the real world. Such enhancements often included information to support a specific task (e.g. providing a maintenance worker with the safety risks when entering the refrigeration section of a processing plant and a checklist that can be completed).

Scientific studies were demonstrating the benefits of AR in several industries, including:

- Online games that employ interactive AR
- Augmentation of clinical procedures in the medical industry with instructions and anatomical features
- Use of AR in archaeology and museums to enhance excavation sites with information about ruins and objects that have been discovered.
- Automotive industry was using heads-up displays to assist drivers.
- AR based heads-up displays were becoming common in fighter jets and used in aircraft maintenance and repair tasks.

In all these applications, AR technologies were being shown to reduce human errors, improve safety outcomes and improve productivity.

3 Project Objectives

As per the final contract agreement, the identified objectives for the project are as outlined below:

This project is designed to evaluate the effectiveness of using Mixed Reality Technologies including Augmented Reality training and IOT technology in five tasks undertaken by a maintenance team within JBS and will include:

1 *Investigating what AR & VR technologies and IoT wearables are available to train maintenance operators within JBS.*

2 *Create the required 'Digital twin' (Digital twin refers to a digital replica of potential and actual physical assets, processes, people, places, systems and devices that can be used for various purposes, in this case training) for 5 tasks undertaken by a maintenance operator.*

3 *Tailor the technology to facilitate a pilot using five tasks maintenance undertake within a processing plant and create a digital twin of the relevant plant areas, overlay the required Safe Work Method Statements (SWMS) and checklists required to be undertaken, highlighting critical technical components of the task, important WHS practices and associated risks and relevant QA safety practices that maintenance need to be aware of, i.e. identifying the confined spaces, electrical hazards, etc. and deliver this information to the operator in spatial context.*

4 *Conduct the pilot program using the technologies or various technologies.*

5 *Design a research-based evaluation system to compare the training delivered to the maintenance users (traditional methods vs AR vs VR).* (JBS Australia/ AMPC, 2020, p. 5)

Pending evaluation, it was anticipated that these activities had the potential to deliver a range of significant benefits to the industry, including:

- Greater effectiveness and improved efficiency of training delivery.
- More detailed and focused training of staff without exposure to site risks at a vulnerable stage in their development (e.g. exposure to heat and moving components).
- Increased focus on risk mitigation.
- Just-in-time availability of training materials for typically infrequent tasks, including enabling reinforcement of previous learning.
- Ability to address challenges associated with delivering training across multiple languages.

At the outset of this project, it was anticipated that the pilot would identify a number of other applications where the technology could be applied into the future.

4 Methodology

Due to a range of factors, including implications of restricted travel arising from the COVID pandemic, the final methodology engaged for this project differed somewhat from the initial planned methodology. This section gives an overview of the planned methodology, an explanation of challenges impacting on delivery and the resulting methodology used.

4.1 Planned methodology

The methodology for this project, as documented in the final contract agreement (JBS Australia/ AMPC, 2020) is outlined below:

1 *Investigate what technologies are currently available and host meetings to evaluate the proposed technologies.*

2 *Identify and commit to the five maintenance tasks and location of the Pilot program.*

3 *Overlay the digital twin with critical processing information, SWMS, WHS information, QA information and relevant checklists based on the traditional e-learning material.*

4 *Conduct the pilot over the agreed period of time with the maintenance team.*

5 *Design and deploy a research-based evaluation to compare the learning outcomes using traditional training (i.e. current paper-based systems and e-learning) compared to Mixed Reality Technology and the compliance of safety documentation.*

6 *Final report including an evaluation of further uses within maintenance departments and the wider Red Meat Industry.* (JBS Australia/ AMPC, 2020, pp. 4-5)

4.2 Actual methodology

Due to a range of circumstances, the planned methodology outlined above was unable to be adhered to. Following discussion between JBS Australia and the AMPC, a new methodology was agreed to enable project finalisation.

The following table provides an overview of how the actual methodology varied from the original methodology, including the rationale for changes.

Planned Methodology		Actual Methodology	Rationale/ Comments
1	Investigate what technologies are currently available and host meetings to evaluate the proposed technologies.	No change	N/A
2	Identify and commit to the five maintenance tasks and location of the Pilot program.	No change	N/A
3	Overlay the digital twin with critical processing information, SWMS, WHS information, QA	No change	N/A

Planned Methodology		Actual Methodology	Rationale/ Comments
	information and relevant checklists based on the traditional e-learning material.		
4	Conduct the pilot over the agreed period of time with the maintenance team.	Evaluation based on project team experiences and literature review findings.	COVID restrictions prevented project team members from travelling to the pilot site in Melbourne from Brisbane. An evaluation survey (see Appendix 1) was developed to facilitate pilot evaluation but was unable to be utilised.
5	Design and deploy a research-based evaluation to compare the learning outcomes using traditional training (i.e. current paper-based systems and e-learning) compared to Mixed Reality Technology and the compliance of safety documentation.	Literature review undertaken to provide analysis of current state and utilisation of mixed reality technology for workplace training.	Inability to conduct an evaluation of the technology developed led to an agreement to undertake a literature review instead. This change had the added benefit of being able to provide a more current overview of available technologies and their effectiveness, given there had been significant advancement in technology since the outset of the project.
6	Final report including an evaluation of further uses within maintenance departments and the wider Red Meat Industry.	Final report to be provided, but with increased focus on literature review and project team members over planned evaluation.	The final report will still provide valuable information to the industry re the suitability and effectiveness of mixed reality technology in workplace training, including valuable learnings.

5 Project Outcomes

The final contract agreement incorporated the following five milestones:

Milestone	Due Date	Description
1	30/10/20	• Investigate what technologies are currently available and host meetings to evaluate proposed technologies. • Identify and commit to the five tasks and the maintenance team for the pilot program to be conducted.
2	14/5/21	• Overlay critical task information, SWMS, WHS information, QA information and relevant checklists based on the traditional e-learning material into an Augmented Reality experience.
3	2/8/21	• Conduct the pilot over the agreed period of time with the maintenance team.
4	30/9/21	• Research design developed to evaluate the comparison of training methods and conduct study.
5	29/10/21	• Snapshot and Final report submitted.

As per the changes in methodology outlined in Part 4 – Methodology, following consultation with AMPC it was agreed that milestones three and four would be replaced by:

- Capturing learnings from project team members and other JBS Australia team members in relation to their experiences with the technology
- Completion of a literature review that provides updated information about available technologies and utilisation.

Project outcomes are summarised below against the revised Project Milestones.

5.1 Milestone One

The first milestone of the project had two core elements, technology evaluation and task identification.

The technology evaluation component involved identifying the potential new technologies that could be used to communicate important information about how to complete a physical maintenance task in the plant safely. Evaluation of each of these technologies against a set of criteria and ultimately determining which technologies was planned for inclusion in the Pilot Program.

In addition to selecting the technologies to be tested, market research was carried out to identify potential vendors with suitable capabilities to implement the selected technology in the Pilot Program.

The program required five tasks to be used as a basis for applying the new technologies. The selection of these five tasks was part of the first milestone objective.

5.1.1 Technology Evaluation

The existing process incorporated employees being provided information about how to carry out a task through a combination of documentation, offsite training, onsite training and on the job training. In some cases, task execution information was well documented, in others knowledge was largely gained on-the-job.

In an industrial setting, all mechanical tasks have two elements, the steps required to technically execute the task and the preparation that must occur to ensure the task is carried out with the minimum practicable risk.

An overdependence on informal transfer of knowledge where operators “learn from others” presented an opportunity for technology to deliver more formal, structured learning providing greater consistency in performance.

When considering and evaluating potential technologies, the project sought new methods to deliver information to the plant operator to complete their task. Importantly, it sought to provide information beyond the sequential steps to complete the mechanical task, making them more aware of their surroundings, the potential hazards that exist and the associated risk mitigation activities that must also be completed in a more effective method.

Traditional Methods (eLearn)

The most common method of documenting instruction to a worker is through a Standard Operating Procedure (SOP) or similar written documents. These can be delivered in paper or digital versions. These documents may have diagrams and other instructional aides, however, fundamentally involve operators reading (and interpreting) text, absorbing (some) information and then attempting to retain their interpretation of the information they managed to absorb until they are required to complete the mechanical task. In general, operators would read instructional information in a training or educational setting at a time significantly (days to weeks, if not months) prior to carrying out a task. The information is not provided in a timely or spatially relevant manner.

Virtual Reality

Virtual Reality or VR is an immersive 3D tool that enables the recreation of a real-world (or fictional) environment in a controlled virtual experience. This enables the consumer to experience a simulated version of the task they seek to carry out and become familiar with each of the steps they must complete. VR is exclusively delivered through a headset that effectively isolates the user from their surroundings. The digital, 3D virtual environment is very flexible and information can be conveyed to the user using many visually stimulating techniques. For example, a hot pipe can be shown in red or moving machinery can have large hazard warning signs in the immediate vicinity. Such indicators would not be practical in the real-world. This virtual environment allows the user to experience a very realistic simulation of the task they are training to do that can be further enhanced for learning purposes. This highly visual and realistic nature improves the retention of information. However, by definition, VR is ‘virtual’, hence is typically consumed at a time and place separate to where and when the actual real-world task will be executed. While the information can be delivered in an incredibly contextual manner, it still requires the user to retain all of the information consumed until they carry out the real-world task.

Augmented Reality

Augmented Reality or AR involves providing additional information to the user in the context of their real-world environment. Fundamentally, AR requires the user to be located in the actual environment for which the AR experience applies, i.e. standing in the plant operating room. AR experience can be delivered in many ways, typical methods involve using phone or tablet devices with screens and cameras, or more advanced wearable headsets providing a 'heads up' display. Like VR, AR has the ability to convey information in almost any format, be that text, 2D diagrams, movies, sound or 3D models. Any of these formats can be 'layered' over the user's view of the real world to 'augment their reality' and provide highly targeted and timely information in spatial context. AR is incredibly powerful for providing easy to consume information at the right place at the right time.

Evaluation Criteria

Criteria	eLearn	Virtual Reality	Augmented Reality
Simplicity of hardware	★★★★☆	★☆☆☆☆	★★☆☆☆
Ease of consumption of information	★☆☆☆☆	★★★★★	★★★★☆
Timing of delivery of information	★☆☆☆☆	★★☆☆☆	★★★★★
Contextual delivery of information	★☆☆☆☆	★★★☆☆	★★★★★
Current adoption in industry?	4/5	1/5	0/5

Summary of technology evaluation

Based on the evaluation of the above technologies Augmented Reality was identified as a clear leader. Its' ability to deliver highly visual information at the right time in spatial context has considerable potential to change not only how employees learn, but they are continuously reminded about task information while 'on the job'.

Variation to technology evaluation

During the implementation phase of the project, it became evident that there were considerable limitations with Augmented Reality technology and it was hypothesised that Augmented Technology would be more effective if used with Virtual Reality technology. That is, an operator can be trained in VR and then use AR for task executional support. As a result of this, the project was extended to leverage existing content, developed for AR, to also deliver training examples for the same five tasks in VR.

5.1.2 Vendors

The Design Technology Company (DTCo.) based in Melbourne was identified as a highly suitable partner for this pilot program. DTCo. has a very strong industrial background with the majority of their work focusing on mechanical 3D modelling and drafting in industrial plants. More recently DTCo. had focused on extracting more value from 3D data, this had led to capabilities in capturing existing environments, creating models (where required) then consuming the hybrid environment of the reality captured and 3D models through VR and/or AR. DTCo.'s industrial background and familiarity with plant operations placed them in a unique position to implement an AR solution in a highly practical way.

5.1.3 Task Identification

Maintenance tasks undertaken in the Brooklyn engine room in Melbourne were identified as having potential to gain benefit from the pilot with five suitable tasks subsequently identified in the Brooklyn, Victoria plant's engine room, as outlined in the following table.

Task	Title	Overview
1	General Area Induction	The first task involved creating a general induction to the 'engine room' at the Brooklyn, VIC plant. The experience sought to familiarise the user with their surroundings in the engine room, identifying equipment, hazards, safety equipment, plant operational characteristics such as fluid flow directions and pressures and complete a safety check on entry to the area.
2	Compressor Inspection	The second task involved a more detailed interaction with a specific piece of equipment. This AR experience involved the identification (and acknowledgement) of relevant hazards in the area, then detailed, step-by-step instructions were provided to check the oil level in compressor and inspect other key pieces of equipment in the vicinity to ensure functionality.
3	Changing Filter	The third task involved mechanical disassembly and reassembly of equipment. Specifically, the change of a filter on a compressor in the 'engine room'. The experience navigated the user to the relevant area, instructed the user how to navigate the relevant hazards and isolate the equipment, then provided step-by-step instruction to disassemble the equipment, carry out inspections, change the filter and reassemble and bring the compressor back online.
4	Valve Refurbishment	The fourth task involved the disassembly and in-situ refurbishment of a standard valve. Again, the experience guided the user to the relevant valve in the 'engine room', assisted in isolating the valve and identify other hazards in the vicinity. The experience then provided detailed instructions for valve disassembly and reassembly with new seals.
5	Draining Oil	The fifth task aimed to be a more generic task of draining oil from the ammonia system. In this experience we sought to demonstrate how other data can be delivered in AR. In this case, a simulated parameter of *'days since last oil drain'* would be applied to the drain points in the engine room. The user would be able to quickly identify a drain point that had not been drained and needs draining based on the data. Generic instructions about how to drain the oil were provided, however not in spatial context.

The selection of these tasks for the purposes of this assessment was not trivial. Three criterial were used to identify a suitable task:

- The task had to be sufficiently complex to warrant the use of additional technology to guide the operator

- The task had to be in an area of sufficient geormetry to support the application Augmented Reality tracking technologies such that the AR experience could be reliably delivered to the operator
- The task has to be mechanical/physical in nature such that 3D augmentations would provide meaningful additional information to the operator – i.e. not just using complex technology to deliver a 2D written instruction in a highly complex way

Ideally, it was desirable that the task selected would also have the following characteristics:

- Many people would have to carry out this task, hence a statistically significant sample size of operators could be established for evaluation of effectiveness
- There would be a sufficient number of operators who do not currently have knowledge about this these tasks available to test the application of the technology on

In addition to the above, it was difficult to establish exactly what the specific steps were for each task identified. Essentially, all operators had slightly different ways of doing thing, as a result it was difficult to get a clear understanding of what content/instructions should be incorporated into an experience. This is a key learning for future experience development. It is critical that all stakeholders are aligned on the content of the experience. This applies to the development of any training content, regardless of delivery method.

5.2 Milestone Two

Milestone Two focused on creation of the Augmented Reality experience with the overlaying of critical processing information, Safe Work Method Statements (SWMS), Workplace Health and Safety (WHS) information, Quality Assurance (QA) information and relevant checklists based on the traditional eLearning material. In addition, the revised project scope included a Virtual Reality experience demonstrating the same instructional parameters.

As the main focus for this milestone was to create digital experiences directly relating to the working/ training environment, engaging an external provider was essential to leverage the appropriate digital platforms to build the training experiences. Significant expertise and testing were required to create effective VR and AR training experiences.

To create the relevant AR and VR experience of the Brooklyn, Victoria engine room the following method was used:

1. The site was captured using Matterport scanning technology enabling easy access to site details including dimentions and aesthetic details.
2. The 3D data from the scan was used in the Unity game engine as both a ‘target’ to align the AR headwear to the environment (necessary for consumption of AR experiences) and as a ‘3D map’ to facilitate the accurate placement of augmentations during development
3. Using the Matterport scan data as a guide, a new, completely virtual environment was created in the Unity game engine to support a VR experience
4. Software applications were then built for both the VR and AR outputs. VR was built for Pico Neo 3 headsets, while the AR was built for both tablet devices and Microsoft Hololens 2.

Following confirmation of the tasks to be incorporated in training as part of Milestone One, Milestone Two incorporated successful execution of the activities outlined below.

5.2.1 Matterport Scan

Matterport is a space-scanning tool that can create immersive 3D "digital twins" of a room (or entire building). This kind of 3D scanning is often used for architectural and real estate projects as well as provision of virtual tours.

In this instance, DTCo. created a Matterport scan of the Brooklyn engine room, providing a digital twin of the room from which training activities could be built.

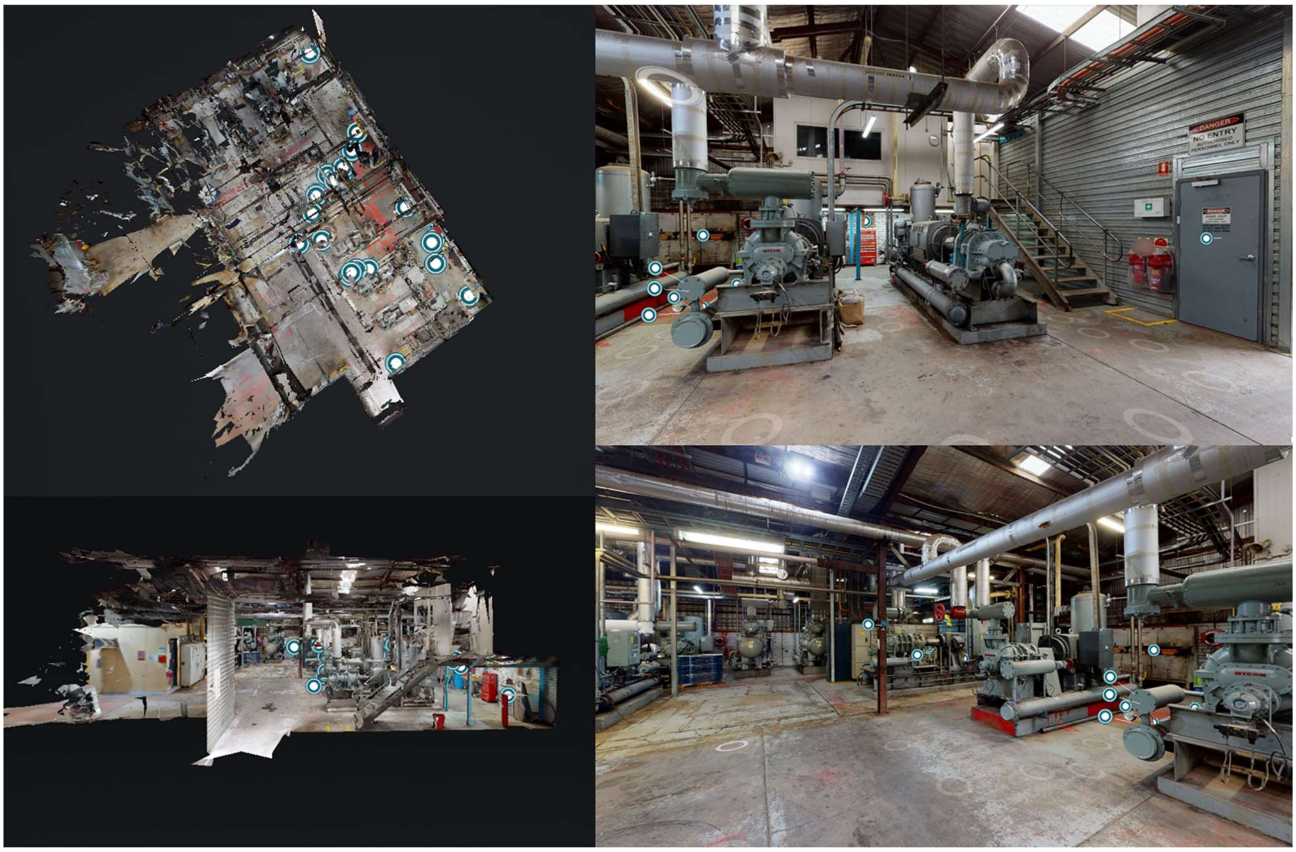


Figure 3 - Matterport Scan

5.2.2 Augmented Reality Model

The next step was to create an Augmented Reality experience (see Figure 2), including Simultaneous Localisation and Mapping (SLAM) and aligning augmentations with the real environment (for both fixed objects such as machinery). The Augmented Reality experience could be consumed through a device (wearable heads up display or tablet) while in the actual location – the Brooklyn engine room.

Augmented Reality was initially identified as the desired technology to deliver instructions to the operator. In order to build the AR experience there are two key elements that were needed:

1. A method for aligning both the virtual elements (i.e. augmentations) and the real world, more commonly referred to as tracking; and
2. Augmentations to align with the real world

Figure 4 - Augmented Reality Experience

This was achieved by using the Matterport scan and integrating with Vuforia Engine in the Unity game engine. Effectively we were able to create a ‘target’ that the AR device (Hololens, tablet, etc.) would look for when in the room. Once the device identified the ‘target’ it was able to align augmentations with the surrounding real world.

In addition to providing a ‘target’, the Matterport scan also provided a sufficiently accurate ‘map’ of the real work environment in the Unity development space, such that augmentations could be quickly and accurately located and programmed to be visible at the right times in AR experience.

In some areas there was insufficient detail in the Matterport scan in these areas DTCo. created additional detail by creating photogrammetry models of key components and amalgamating that data with the 3D data from the Matterport capture.

During this development onsite testing was carried out with both project team members and also engine room operators from JBS. One of the key limitations that was identified was the narrow Field of View (FoV) in AR, regardless of device (i.e. wearable or tablet). This created two challenges:

1. The FoV quickly became crowded and occluded the real world - a potential hazard
2. If the augmentation was not immediately in the user’s FoV, or at least nearby, then it was often difficult for the user to find the augmentation and follow the relevant instructions

Both of these challenges could be overcome with improved user experience (UX) design and some solutions were tested. For example, initially guidance around the room was provided to the user by placing footprint augmentations on the floor, however we discovered this in fact occluded the floor and the user could no longer see where they were placing their feet. An alternative approach was to provide a small arrow in the middle of the FoV (static) that would ‘direct the gaze’ of the user, then a scalable balloon would exist at the new location. That is, the arrow would guide the user to look for the balloon then, once located, they were able to walk to the balloon (which would reduce in size when approached) without additional augmentations occluding their walkway. This solved both occlusion management and also guiding the user to the next relevant augmentation. Further development and testing could further optimise this from a UX point of view and make the experiences more intuitive to consume.

During the development of the AR experience the general consensus from the project team and plant operators was that it was unlikely that a user without prior, task specific training would use an AR experience alone to guide them through a task. This was largely due to the fact that too much information would need to be built into an AR experience and then consumed by the operator at the time they were doing the task. It was hypothesised that a better solution would be a combination of VR training and AR support for task execution would be a more effective use of the available technologies. This hypothesis gave rise to the scope review and hence inclusion of VR training experiences in the pilot project.

5.2.3 Virtual Reality Model

The Matterport scan was used as a guide to create a completely virtual model of the engine room (Figure 2 below). In this instance a 3D CAD package was used to 3D model much of the details in the scan. This was achieved by downloading a 3D point cloud from the Matterport scan and using it as a reference when creating new 3D models. These models were then imported into the Unity game engine. Here, textures could be applied and some optimisation was carried out to ensure the experience would perform adequately on a portable VR headset (i.e. Pico Neo 3, Oculus Quest, HTC Vive Focus etc.)

In addition, all interactions between the user and the virtual space were created in Unity. For example, users were required to put on PPE prior to entering the room, or virtually pick up a spanner and use it to open a valve. Importantly, this experience (application) was created to be stored locally on the standalone VR headsets, meaning that it could be consumed by a user in any location.

Some challenges were encountered in the optimisation process, particularly around the number of polygons (small shapes) used to make up the scene. Much of the geometry of the scene was created in 3D CAD with a focus on detail, particulary around the machinery, so that it could be used for assembly/operational instructions. This detail made the 3D models heavy and in hindsight, it would have been better to create simpler models of the majority of the components in the scene and increase realism using game development techniques such as image wrapping and light baking.

An adequate VR experience providing instruction on the five tasks was created, however as with all pilot programs there is room for improvement on the optimisation of the experience and the quality of the interactions within it.

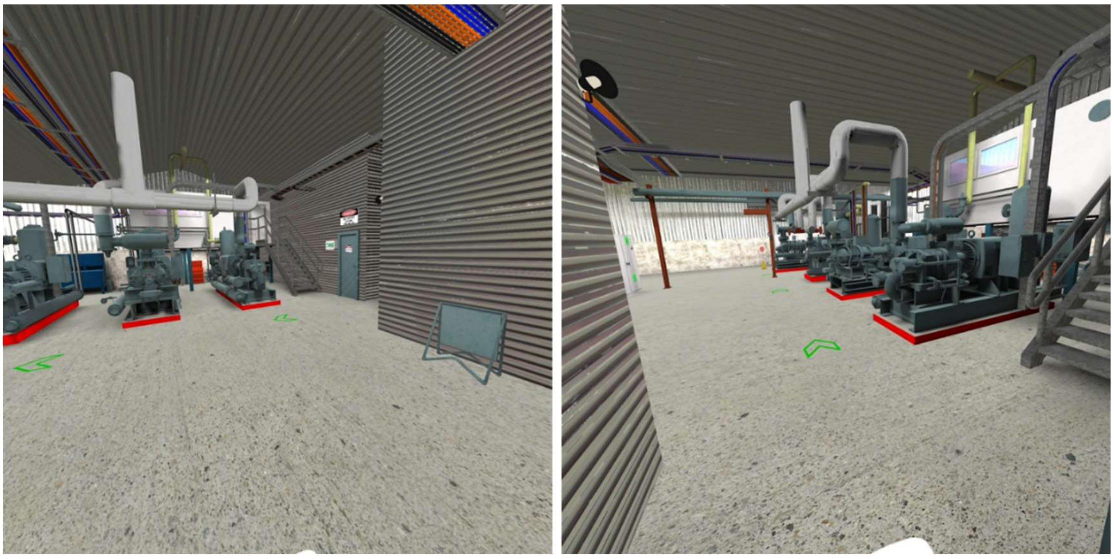


Figure 2 - Virtual Reality Experience

The final step in this milestone was to overlay SWMS, WHS and QA information onto both the VR and AR models with navigation arrows and location assistance methods to assist with task location (see Figures 4 and 5).

Figure 5 - VR Environment with Overlays

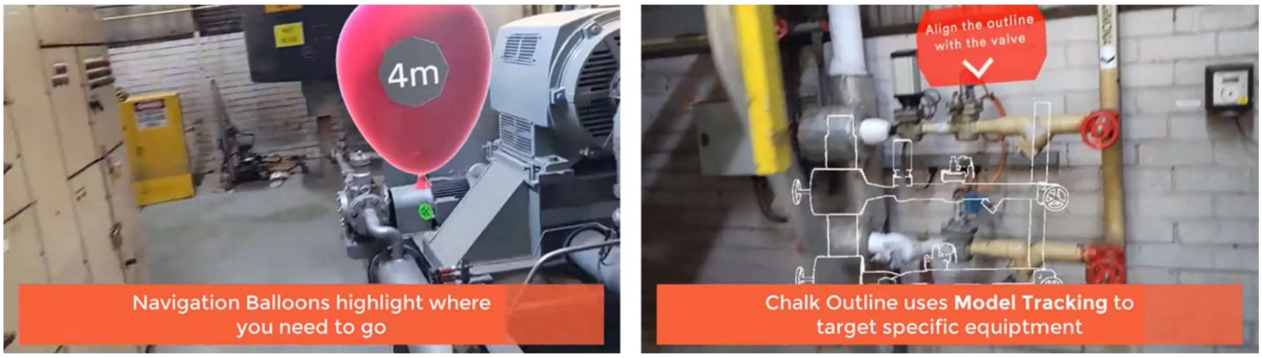


Figure 6 - AR Environment with Overlays

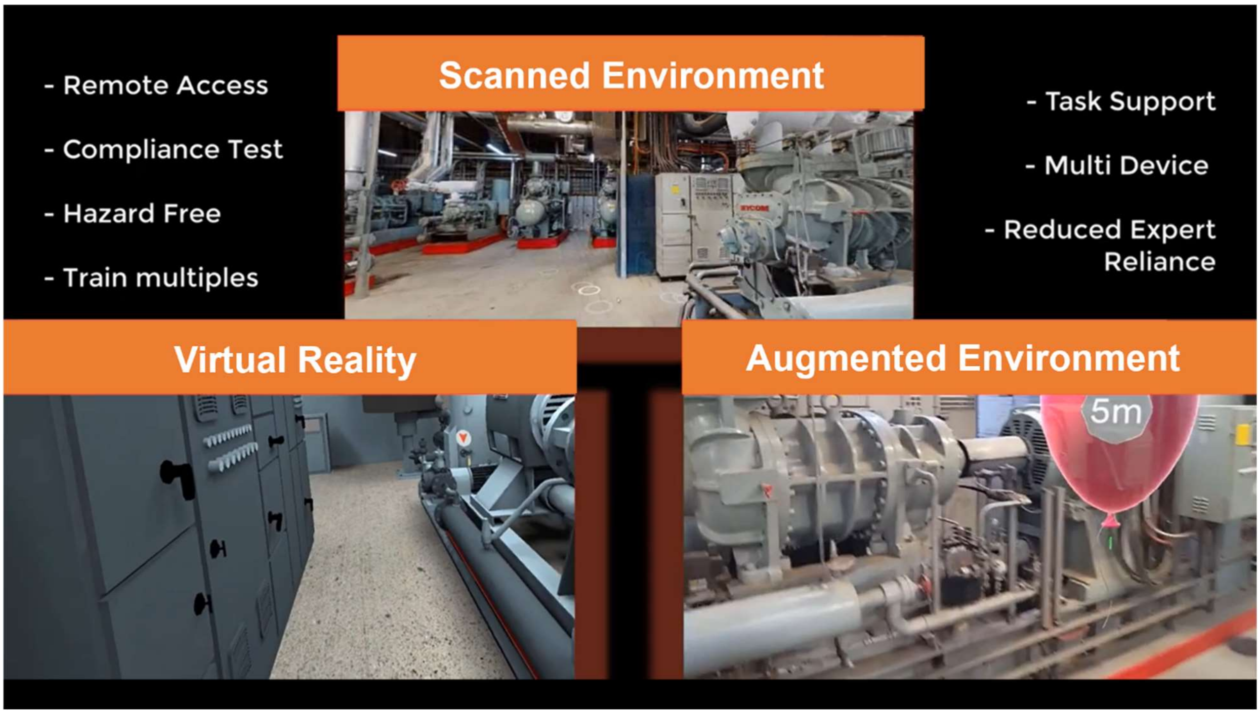


Figure 7 - Overview of Environments

Delivery of Milestone Two components was successful and provided substantial demonstrations of the potential for the technology to be tailored to suit training needs unique to individual sites. The implementation validated workflows from scanning through to 3D content creation and implementation in VR and AR interactive experiences.

Additional opportunities identified through this milestone included:

- Potential to use Internet of Things (IoT) to capture additional data to feed into the Augmented Reality experience (e.g. temperature through thermal monitoring)
- Potential to incorporate gamification elements to further enhance the training experience and embed learnings

As noted in Task Identification, there were considerable challenges in identifying tasks that met all criteria to be suitable for developing AR experiences. As a result, it was difficult to obtain sufficient participants to complete the evaluation activities, scheduled for Milestone Three, due to the relatively small number of people who would typically be appropriately skilled to carry out these tasks (5). In addition, the finding that AR could not be used as a stand-alone tool to guide an operator to execute a task they have not been trained in meant we could not expand the assessment to other stakeholders with no relevant experience.

5.3 Milestone Three

Milestone Three was intended to conduct a pilot over an agreed period of time within the maintenance team. However, as outlined earlier, travel limitations arising from the COVID pandemic, as well as the limited number of people able to participate in the pilot (as discovered in Milestone Two) resulted in negotiations with AMPC and a change in approach.

Instead of a comprehensive evaluation, it was agreed that the valuable learnings and observations already identified by project team members, as well as anecdotal feedback and reactions from people who used the technology would be summarised and presented.

5.3.1 Project Team Learnings and Observations

The following is a summary of key learnings and observations experienced by project team members when accessing the VR training program.

NB: This section does not include learnings and observations related to the process of developing MR training modules, nor those associated with the project itself. For information about these matters, refer to 6.0 Discussion. The information in this section is related to the experience of team members in utilising the developed VR training tool.

- **Powerful technology**

  With minimal previous exposure to VR environments, the project team members were impressed by the immersive nature of the VR environment and could readily see the potential for application in a learning and development complex.

- **Importance of familiarisation**

  As the project team members were initially unfamiliar with the VR environment and utilisation of headsets, it took some time to become acclimatised to the environment. This initially detracted from the potential learning experience, with users more focused on utilising the technology than on learning.

With increased familiarisation, this issue became nearly irrelevant. However, it does point to the need for the design to consider the experience of the potential users and to consider incorporation of time for users to become used to the equipment and environment before commencing learning modules.

- **Potential for distraction**

  Whilst the project was unable to complete the planned evaluation of AR and VR training environments, a small number of team members from the Brooklyn engine room did review the developed programs. Their feedback pointed to the need to manage stakeholder expectations when utilising MR technology in training.

  An early challenge for the developers, DTCo, was to obtain an accurate description of tasks and task requirements due to a lack of up-to-ate documented standard operating procedures. Users from the Brooklyn engine room became focused on the accuracy of the content of the training materials, rather than focusing on the technology and the value of the experience.

  Even project team members, some of whom had been part of the design process, found themselves taking a critical approach to reviewing the training modules, again detracting from the nature of the experience.

  The above comments point to the unforgiving nature of the technology and the potential for distraction. The technology itself is so powerful and so immersive that any "mistakes" or opportunities for improvement are magnified by the experience, more-so than with other training delivery mechanisms.

  A key learning from this is to ensure comprehensive reviews of future training material prior to release and to manage expectations where possible.

- **Physical experiences**

  Project team members initially experienced some motion sickness when utilising the training modules. Again, this experienced tended to improve as users became more familiar with the technological, but did point to the very real need to utilise considered design principles to minimise potential negative physical experiences.

- **Instructional design**

  Project team members trialling the training modules found the initial training programs difficult to navigate in some circumstances. Not being used to the environment contributed to this, however it was noted that design would benefit from more rather than less multi-modal instructions. For example, utilising visual cues to reinforce audio instructions.

  Due to initial motion sickness and challenges in navigation, project team members also felt that perhaps MR training technologies would be best utilised as part of a blended learning program with short immersive sessions. This impression should be the subject of future MR training research and evaluation activities.

5.3.2 Anecdotal Feedback and Reactions

Beyond project team member review of the developed training packages, a range of people from within JBS Australia have accessed the headset technology and VR experience in the past few months.

Overwhelmingly, the majority of people have reacted positively to the technology, impressed by the powerful immersive nature of the medium. However, there seems to be a small proportion of people (perhaps 1 in 10) that struggle with the technology and require significant support to navigate their virtual surrounds.

5.4 Milestone Four

Milestone Four was intended to incorporate a comparison of the different training methods, including comparison with more traditional methods, such as eLearning and classroom style learning. However, due to the inability to undertake an effective comparison using the developed technology outlined in Milestone Two, following negotiations with AMPC it was agreed that a literature review of XR technologies in training would provide a suitable replacement activity.

The literature review incorporated identification and analysis of papers and articles that provided information about current perspectives, utilisation and effectiveness of mixed reality training technologies, particularly in relation to training. Attempts were made to identify items that presented a range of views related to current use of these technologies. Items selected for review are listed below – details and a more comprehensive summary of each item can be found at Appendix One.

Source	Author/ Date	Overview
1. *Workers Rejoice: VR is Turning Industrial Training on its Head*	Higgins, Forbes Magazine, 2021	Provides an optimistic outlook for the potential of VR to provide effective training as well as contribute to employee engagement and retention.
2. *How virtual reality is redefining soft skills training*	Likens and Eckert, PwC, 2021	Referencing a 2020 study of managers across the US using different types of training, this article talks to the advantages and potential of using VR to address soft skills training requirements and provides a positive comparison of the technology with more traditional delivery mechanisms.
3. *Education in the Digital Age: Learning Experience in Virtual and Mixed Realities*	Allcoat et al, Journal of Educational Computing Research, 2021	This paper presents findings from a study examining the effectiveness of VR technologies for use in education, finding that whilst VR and MR resulted in similar levels of performance to traditional learning, both technologies presented higher levels of engagement, with higher levels of positive emotions in the VR condition.
4. *A Systematic Literature Review on Extended Reality: Virtual, Augmented and Mixed Reality in Working Life*	Vasarainen et al, International Journal of Virtual Reality, 2021	Looking at application areas and collaborative uses of XR in real-life work settings, this paper found there are still few cases of actual long-term use of the technologies. XR as a medium was identified as having potential to overcome obstacles set by time and space, safety and resources, especially aiding work requiring shared spatial experiences
5. *Immersive Learning with XR*	Accenture, 2021	This comprehensive article provides a summary of a global 2020 study incorporating over 300 executives across give countries to understand their organisation's utilisation of XR technologies for workplace training. The article outlines the significant advantages of XR learning and highlights potential barriers.

Source	Author/ Date	Overview
6. *XR-Ed Framework: Designing Instruction-drive and Learner-centre Extended Reality Systems for Education*	Yang et al, 2020	This paper talks to the lack of a clear framework to understand different design dimensions in XR training and proposes a framework – XR-Ed - and instructions – XR-Ins – to facilitate an instructional design approach to development of XR L&D programs.
7. *Design and Evaluation of a VR Training Simulation for Pump Maintenance Based on a Use Case at Grundfos*	Winther, 2020	The final item provides an overview of a similar study to this one and incorporates evaluation against the components of completion time, number of errors and confidence in actions.
8. *Lessons Learned From Immersive and Desktop VR Training of Mines Rescuers*	Pedram et al, 2021	This paper discusses results and provides comparisons between two rounds of virtual mines rescue training – the first conducted in a surround projection environment (360-VR) and the second round was conducted in desktop virtual reality (Desktop-VR).
9. *A Review on Virtual Reality Skill Training Applications*	Xie, B. et al	This paper provides an overview of current research efforts and practices associated with VR training for different training applications. Xie et al look at application of VR training, evaluation and likely future directions.

5.4.1 Limited research

A key finding in many of the items reviewed as part of this research, and indeed a finding of this research in itself, is the current lack of comprehensive, statistically relevant evaluations of using mixed reality technology for training purposes.

Research papers on this topic tend by nature to be "reviews of reviews", where the authors analyse existing papers to prove or disprove hypotheses as opposed to undertaking practical technical research in the field. This situation is likely exacerbated by the global pandemic, with limited abilities to complete field evaluations (as was the case with the planned Brooklyn evaluation as part of this project).

For example, Vasarainen et al (4) present a key finding that "there are still few cases of actual long-term use of XR technologies". Further, the paper noted the "differing definitions of XR and its components by various authors, fuelled by the continuous advancement and new applications of technology". The lack of established definitions of key features, such as immersion and interaction, was also noted with the authors concurring that XR is still "technology in the making".

5.4.2 Instructional design

As a further indicator of the lack of research relating to MR technology for training purposes, Yang et al (6) talk to the lack of a clear framework to understand different design dimensions in educational XR systems.

The paper seeks to address this gap by providing a suggested framework and instructions to assist with instructional design based on learning theory.

Further, Yang et al point to the prominence of technical designers being engaged to develop educational materials, often with minimal experience in instructional design.

Accenture (5) also refer to the need for considered engagement of technical experts, noting an XR offering takes more than adding tools to existing workflows and recommends partnering with experts as “immersive learning and XR technology provide unique experiences that require a deep understanding of specific requirements and best practices”. The paper recommends organisations “look for a partner with a unique combination of business and technology experience mixed with industry and functional experience”.

This theme is continued by Vasarainen et al (4) who note that headset use does not automatically guarantee learning, but rather enables access to “situations that are either inaccessible (in time or space) or problematic (dangerous or unethical)”.

Slightly aside from instructional design, but a component that needs to be considered, is the selection of technology itself.

Regardless of XR form, Vasarainen et al noted there are different levels of immersion and interaction, either with the virtual world and its contents or between participants. Headsets were widely used but equally desktop and screen-based solutions were common: occasionally, the most straightforward and simple technological solutions were the most workable. The authors noted that “in a way, we may consider the most powerful technology to be the one that does not draw too much attention towards itself”.

5.4.3 Conflicting results

Perhaps due to the lack of comprehensive, statistically relevant evaluation of MR training technologies in recent years, there appears to be some discrepancies as to the relative effectiveness of these tools.

Reporting on a PwC study in 2020, Likens and Eckert (2) report on the glowing results of a study involving new managers across US locations that completed the same training – design to address inclusive leadership – in either classroom, elearn and v-learn. The results showed that VR can significantly help business leaders upskills their employees faster and more effectively than more traditional methods.

However, in a study somewhat similar to the intentions of this study, Winther (7) reports a surprise in the findings, with participants taking longer in VR training than traditional methods to complete tasks, with more errors and decreased confidence. Winther does still point to the benefits of VR training, particularly in situations that would otherwise present danger or conditions are not readily available (e.g. equipment needs to be shut down).

The conflicting results may again point to the lack of available analysis in the field, particularly in relation to the best application of MR training technologies. It may be possible that MR training is more effective than traditional methods when concerning soft skills, whereas traditional training methods are more effective with regards to manual tasks.

Regardless, studies show that although traditional training methods could potentially be more effective with regard to manual tasks, MR and VR are still able alternatives and sometimes better alternatives when there are difficulties with access to training material.

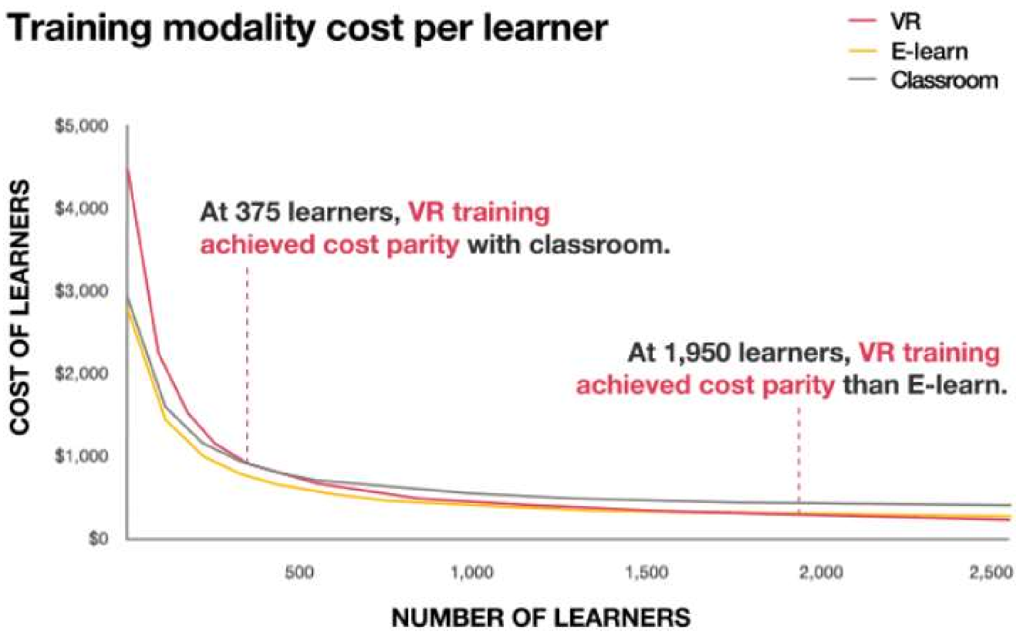
5.4.4 Benefits of XR

Despite a lack of comprehensive research and evaluation, the literature review overwhelmingly points to the benefits of XR in workplace training, such as:

In summarising the Accenture findings, Likens and Eckert (2) talk to the significant value of VR in soft skills training in particular, finding:

- Employees in VR courses can be trained up to four times faster
- VR learners are more confident in applying what they're taught
- Employees are more emotionally connected to VR content
- VR learners are more focused
- VR learning can be more cost effective at scale

Accenture reported cost effectiveness compared to classroom training at 375 learners and cost effectiveness with elearning at 1950 learners as per the diagram below:



Source: PwC VR Soft Skills Training Efficacy Study, 2020

More broadly, Allcoat et al (3) point to the higher engagement and positive emotions found in VR and, through the lens of constructivist theory, conclude that "thus VR and MR, which enable active learning, allow one to experience and test such learner-generated hypotheses, which may be more effective compared to traditional passive learning methods".

Higgins (1) further outlines the promise of VR in the industrial workplace, suggesting that, by replacing analogue training with VR, organisations can create a workforce that "is not only more skilful and more knowledgeable, but also more productive, more engaged and, ultimately, more satisfied".

Even Winther (7), in reporting on surprisingly negative results when comparing VR with traditional training methods, concluded that VR "remains a compelling option, not least due to its purely artificial nature, which enables training of otherwise impossible scenarios, e.g., including products that do not yet exist".

5.4.5 Application

In terms of application of MR training, the following domains are noted by Xie et al (9):

- First responder training
- Medical training
- Military training
- Transportation
- Workplace training

More recently, the value of MR training in soft skills and interpersonal training is receiving particular attention, providing a mechanism for users to practice in a safe environment.

5.4.6 Evaluation

Despite an increase in use for training purposes, research suggests evaluation methods are still in their relative infancy.

Vasarainen et al (4) note that, expecting to see novel ways of collecting research such as the use of a united screen and recordings of virtual content, the authors found applied research methods to be primarily traditional, incorporating interviews, questionnaires and observations.

Yang et al (6) also noted on evaluation, commenting that:

> *Somewhat unintuitively… a lot of educational XR applications do not measure learning outcome, but focus their evaluation more on system usability testing. This may be improved as the domain matures, but researchers note future educational XR applications should be more thoroughly evaluated by employing quantitative and qualitative research methods to assess the students' increase of knowledge and skills as well as the students' learning experience.*

Winther (7) utilised relatively common criteria to evaluate the VR training simulation for pump maintenance, comprising:

- Completion time
- Number of errors
- Knowledge retention
- Confidence in ations

The Technology Acceptance Model (TAM) is another approach used to evaluate the effectiveness of MR training. TAM comprises two independent variables as the main predictors of users' attitude towards the type of training, namely:

- Perceived usefulness
- Perceived ease of use

Variations of TAM have also been used with addition of other elements such as perceived enjoyment and interface style added to the evaluation approach.

Other studies have utilised modifications of Kirkpatrick's Training Evaluation model, tailored to be more relevant to VR training, including:

- Engagement: How engaging and relevant the trainee found the training program

- Comprehension: How well did the trainee retain and comprehend the training materials
- Speed to Competency: How well was the trainee able to apply the information learned
- Outcome: How trainee results contribute to the organization's bottom line

Despite the evaluation method used, Xie et al (9) note the caution of a number of researchers that suggest transfer of learning is highly dependent on factors other than the method in which it is delivered, reiterating the importance of training people on the exact areas/ topics needed for people to learn.

> *The factors relating to trainee characteristics (cognitive ability, self-efficacy, motivation and perceived utility of training), training design (behavioural modelling, error management and realistic training environments) and work environment (transfer climate, support, opportunity to perform and follow-up) are the ones "that have exhibited the strongest, most consistent relationships with transfer of training.*

5.4.7 Future of MR

In terms of the likely future in MR training, research points to developments relating to both delivery and evaluation.

- **Immersion**: Developers are providing more immersive environments that can assist with training, such as sense of smell and heat.
- **Haptic feedback**: From subtle touch sensations to feelings of physical exertion, users experience scenarios as though they've lived them.
- **Motion** capture: The ability to capture actions as they're performed will assist with evaluating training effectiveness and the capability of the user.
- **Biometrics**: Embedded sensors can capture users' vitals and things like emotional stress level whilst eye tracking and facial movements can also be recorded and used to evaluate training effectiveness and user performance.
- **Haptic feedback suits**: Taking the MR experience one step (or more) further are haptic feedback suits such as the Teslasuit. While a VR headset provides a startlingly real simulation of the world, a full-body haptic feedback suit does the same for the world of touch and sensation — hot and cold, rough and smooth, pleasure and pain – with the ability to simulate "everything from a bullet to a hug". Although readily available, this technology is in its infancy and its application remains to be seen.

Other advances relate to accessibility and user experience.

> *We'll have faster, lighter, more affordable VR technology. And advances in smartphone technology (such as better cameras and processors) will mean we can enjoy slicker AR and VR experiences on our phones. And with 5G wireless networks, we'll be able to enjoy them wherever we are in the world.*

Marr, B. *Future Predictions of How Virtual Reality and Augmented Reality Will Reshape Our Lives*. Forbes. 2021

6 Discussion

Key findings emerging from this project centred on the following themes:

6.1.1 Technology considerations

As outlined earlier, despite their similar names, there are significant differences between VR and AR. VR completely alters the surroundings, creating a new environment for users whereas AR will modify the current surroundings.

Rather than create a new scene altogether, AR modifies the environment by adding components or sensory information that enhances the real world. Based on a review of available technologies conducted in Milestone 2, augmented reality was selected as the preferred approach for this project.

However, through the course of the project it became apparent that AR technology has relatively limited application that is best dedicated for specific situations.

The project team's observations were that AR is best utilised for task execution support with reduced content focusing specifically on critical/ high-risk and/ or complex steps. VR, on the other hand, provides a different offering to AR and is valuable as a more general training tool. Subsequently, the project scope was revised to incorporate VR training and AR.

In summary, a key learning from this project has been the suitability of each technology at this point in time:

- VR for training
- AR as a task support tool (in place of SMEs)

Additional learnings/ observations relating to each technology are summarised below:

Virtual Reality	Augmented Reality
An immersive technology that removes the potential for distraction to facilitate improved learning outcomes Able to provide training scenarios that are not possible in the real world Need for familiarisation/ introduction to technology as part of training. This component should be delivered in a non-VR environment. "Slick" user management to minimise disruptions/ distractions (e.g. single sign-on, automatic recognition). Integration with LMS to target training content to user (e.g. manage access and track performance). Consider whether unique or generic environment is required. Generic environment could drastically reduce costs.	Suited to training employees in specific tasks, providing opportunities for practice Enabling employees to practice in an augmented environment reduces demand for subject matter experts Robust tracking is essential, AR experience must reliably align to real world in a stable manner. Further development in UX design is required. While some issues were improved in this project, AR in 3-5 years will look considerably different to the experience today. AR can be overwhelming with a need to limit the amount of information flowing to the user to a manageable level. That level is yet to be clearly understood.

6.1.2 Benefits of MR

There are significant benefits to be obtained from the utilisation of MR for training purposes.

- **Skills shortages**: Organisations globally are currently affected by two major issues in relation to skilled workers – availability of workers due to a gap between retiring baby boomers and new workers entering the workforce and the constant need for new skills sets being driven by changes in technology. In this context, organisations must innovate. Reducing dependence on skilled trainers and training venues, MR provides one of the solutions to addressing this challenge.
- **Rapid deployment**: Further aiding skills shortages challenges, once hardware is readily available, MR is more rapidly deployed to workers than traditional methods with training resources able to be distributed to multiple users at multiple locations almost immediately following development.
- **Subject matter experts (SMEs):** By providing a comprehensive level of detail in real-world environments, MR training can reduce dependency on SMEs, a benefit that is likely to become increasingly relevant in the current challenge to obtain and retain skilled workers.
- **Faster learning:** Research by PwC indicates that VR training takes less time than classroom and e-learning courses, contributing to the cost-effectiveness of MR training as well as providing more skilled workers, faster.
- **Difficult training scenarios**: In particular, MR training provides an alternative to situations where training may be dangerous and/ or dependent on certain factors, such as shutting down of equipment.
- **Remote learning:** As a result of COVID-19 and the need for employee social distancing, VR has become a good training alternative to classroom courses.
- **Potentially more effective:** Individuals who are trained using MR may need less time to understand concepts, are less distracted, and may have more confidence and emotional connection to the content.
- **Employee engagement**: MR training is also likely to increase employee engagement through utilisation of more modern and novel learning approaches and greater engagement of learners.

6.1.3 Limitations of MR

Despite numerous benefits as outlined above, research suggests there are some negatives to be aware of in relation to MR training.

- **Physical side effects:** Research demonstrates that some people experience physical side effects when using VR, including headaches, nausea, and eyestrain. However, many of these effects can be overcome with careful design of the training program, hardware selection and delivery.
- **Perceived high initial costs:** VR solutions can have higher costs than other solutions requiring costs associated with hardware, software, technical expertise, etc. However, as MR becomes more popular, development costs and headset prices are decreasing and significant savings can be achieved through scale.
- **Changing market:** More a caution than a limitation, as the MR market is changing and growing so rapidly, organisations need to make considered decisions which can be costly if heavy investment is made with one provider that is then usurped by emerging capabilities and technology.

- **Technology dependency:** If an entire training curriculum is based on VR and the technology breaks down for some reason, learning would stop.
- **Lack of human interaction:** Since people learn differently, it can sometimes be difficult to understand what someone did well or what they did wrong without human interaction. In addition, the lack of human interaction in training in a world that has recently experienced social isolation can be a negative.

6.1.4 Cost-effectiveness

Whilst incurring initial set-up costs, research suggests MR training presents a cost-effective alternative to traditional training when delivered at scale. Once designed, a training package can be reused multiple times, as can the hardware itself once purchased.

Research suggests the technology is cost-effective at scale with PwC finding VR training is cost effective when compared to classroom training at 375 learners and with elearning at 1950 learners.

Whilst there is a lack of generalised findings, individual studies point to greater cost-effectiveness of MR training in situations that require special circumstances (such as production shut-down) or can be dangerous.

One learning from this project was the potential to produce VR training experiences at a more cost-effective rate through the use of a generic environment. Whilst this particular project required specific representation of an actual environment, it is likely other training needs do not require such a unique setting. This would eliminate the need for a Matterport scan and enable reuse of the generic environment for a range of VR training purposes.

6.1.5 Suitability

Research suggests that consideration should be given to the suitability of MR for training purposes. Like all training, design should be based on the subject content and the required transfer of learning to determine the most effective delivery mechanism.

In terms of when to use MR for training, it seems that the most suitable (and cost-effective) scenarios are when:

- **It's impossible**: VR enables users to train in environments that are not able to be trained in traditional ways. For example, putting out fires during fire bans or facilitating a performance management discussion. This can also relate to delivering training that is not able to be delivered in person, as was often the case during the pandemic.
- **It's expensive**: MR has a place when alternative, real-life training is expensive, such as requiring shut-down of equipment and production.
- **It's dangerous**: VR provides a safe place for users to undertake dangerous activities in simulated environments, such as potential consequences of not following procedures when releasing cattle into a feedlot.

MR has also shown itself to be suited to particular types of training. As summarised earlier, AR tends to lend itself to demonstration and practice of complex technical tasks, reducing the dependency on SMEs. VR has different applications and is currently being used effectively primarily in domains such as:

- First responder training
- Military
- Medical
- Construction
- Transportation
- Workplace safety
- Recruiting and onboarding
- Soft skills development

The utilisation of VR to facilitate soft skills development has recently shown significant promise. Training of soft skills like change management, leadership, empathy and creativity all lend themselves to a VR approach. VR provides the ability for users to be put in situations that they otherwise would not be able to experience, from being able to provide performance feedback to team mates to being the subject of bullying or racial abuse. The value of VR in this context lies in the ability to generate an emotional response in participants, creating a sense of empathy.

6.1.6 Design

Due to the immersive nature of the technology, careful design is an imperative for effective MR training. Key aspects that should be considered are outlined below:

- **Motion sickness**: For the immediate future at least, the risk of motion sickness amongst participants is very real. This needs to be addressed through considered design of the technology itself, and in how it is delivered.
- **Blended learning:** Given the relative inexperience of many audiences with the technology, it may be best to introduce MR training as part of a blended learning approach where participants spend short amounts of time using the technology.
- **Familiarisation:** Whilst MR technology remains a new experience for users, it is important that any MR program ensures adequate familiarisation with the technology. It's recommended that this occur in a non-tech environment.
- **Multi-modal cues:** MR technology can be overwhelming for many users. Due to this, learners may miss important cues (e.g. audio instructions). This project has identified the need for multi-modal cues (e.g. audio and visual) to overcome this challenge.
- **Accuracy:** As any errors will be magnified to the user, it is vital that the tasks being outlined and the environment in which the training is situated are as accurate as possible.

The imperative of design in MR training leads to the question of professional expertise.

Many articles talk to developers with minimal instructional design experience developing MR training packages, however great instructional design in a traditional environment does not necessarily translate to great instructional design in VR.

There is a need for a new set of skills amongst technical experts in the field of MR – both developers and instructional designers. Because of the extensive range of technologies and of applications, projects need to have access to both resources. Further, these resources need to work collaboratively to develop the most effective approach to the need at hand.

6.1.7 Expertise

Further to previous discussions and the point above, expertise is potentially required from three fields to create an effective MR training experience, as represented in the diagram below.

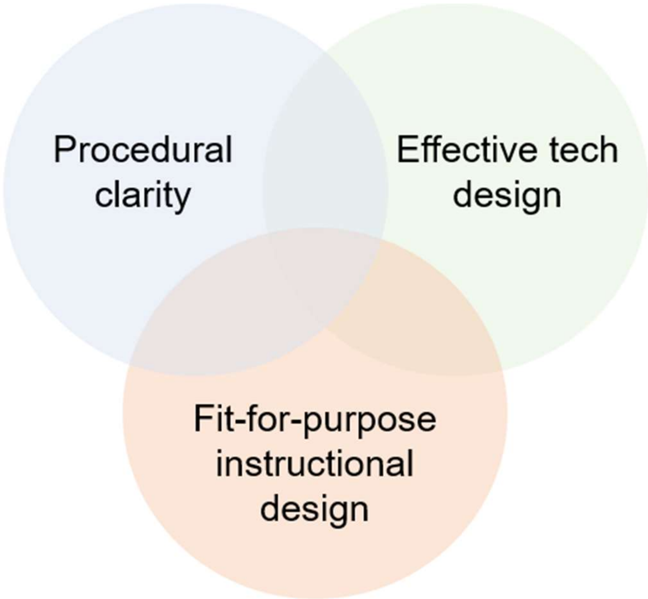


Figure 8 - MR expertise requirements

In pursuing development of a MR training experience, organisations need to ensure they have access to all of the above areas and that representatives from each field are willing and able to work collaboratively to produce the desired outcome.

6.1.8 Deployment platforms

The MR market is essentially segmented into hardware manufacturers and software developers. The software developer market can be further segmented into platform providers and content developers.

As outlined earlier, the technology related to hardware is changing at a rapid pace and is likely to do so for the foreseeable future. Organisations need to be mindful of not overinvesting in one product, generating a short-term wave of interest but ultimately losing momentum and ending up with what can be expensive hardware sitting on the shelf. Organisations need to ensure that investment goes beyond the novelty of a device to deliver identifiable value to users and the business.

In addition to purchasing technology and designing content, organisations need a platform from which to deploy their MR training experiences. MR platforms for entertainment and gaming have been in existence for some time. However, it is only more recently that demand has focused on the need for effective platforms to manage organisational MR programs. Subsequently, platform providers in the context of corporate training is a relatively new space and less mature than the hardware realm.

It is an important aspect to consider, however, as smooth deployment of MR training and in turn the training experience is largely dependent on the capabilities of the platform.

Organisations need to consider what their approach is to content development (in house, outsourced, etc) and how this content is best deployed, including things such as single sign-ons, single portals, and accessibility. Compatibility is another important consideration between hardware and the platform. Hardware decisions will in turn likely impact the options re platforms.

Again, this is an area of limited maturity and minimal available guidance, with many start-up organisations promising the world but not necessarily able to deliver.

6.1.9 Industry maturity

A key finding of this project has been the relative immaturity of the industry. This is evident in the lack of quantifiable studies on effectiveness of technology and on the lack of supporting design and evaluation frameworks.

Due to the breadth of technology available and the pace at which new technology is being created, it may be that the industry remains "immature" in nature for the foreseeable future. It is difficult for useful generic studies to be undertaken with such variability in approaches.

Organisations need to be prepared to operate within this context. This requires certain critical approaches, including:

- **Technical expertise**: It's advised that organisations wishing to develop MR training materials engage professional advisors with relevant experience, both from a technical perspective and from an instructional design perspective.
- **Considered purchasing**: Organisations need to be cautious of over investing in any one particular hardware or software in the current environment.
- **Sharing organisational learning**: Organisations should build on the relative experiences of individual projects and ensure learnings across different MR technologies are shared, as well as sharing of effectiveness in design and delivery approaches.
- **Monitoring of emerging tech**: There is a need for organisations to be aware of current and evolving technology. Consideration should always be given to "what comes next" as what seems like years away is likely to happen sooner than expected. Implications of technological advances such as 5G and
- **Monitoring of emerging frameworks**: There is a need for industry-wide frameworks to guide MR training design and evaluation approaches. Organisations should monitor studies in this space and look to adopt as appropriate.

7 Conclusions / Recommendations

This section itemises project conclusions and associated recommendations for the AMPC and its individual member organisations.

7.1.1 Powerful technology

Mixed reality technologies present significant potential to improve organisational learning outcomes and deliver training in scenarios that would otherwise be inaccessible (e.g. dangerous, costly).

Far from a fad, the technology, in its ever-changing form, is in no doubt here to stay – with studies showing the technology is cost effective at scale and has the potential to deliver improved learning outcomes within shorter timeframes.

This presents a significant opportunity for organisations in the red-meat industry, particularly in terms of rapid deployment of training to remote locations.

Organisations need to take a strategic approach to how they utilise this technology to maximise benefits and avoid potentially costly mistakes (such as over-investing in outdated hardware).

RECOMMENDATION 1.

The industry and its individual organisations need to consider not if, but when and how they will integrate mixed reality training technologies into their learning and development offerings.

7.1.2 Considered use

The potential benefits of MR to improve learning outcomes are only likely to be realised with considered use of technology. As noted earlier in this report, headsets alone will not deliver effective training.

The focus of training must remain on the desired learning outcomes and not be distracted by novelty approaches that could, if not used appropriately, result in expensive programs that deliver minimum benefit.

Consideration needs to be given to items such as:

- Whether MR is a suitable training mechanism for the desired learning outcome
- What technology best fits the purpose of the training (e.g. 360 degrees video vs AR vs VR)
- How the technology might best be delivered (e.g. as part of a blended learning program)
- What steps will be taken to prepare learners to utilise the technology

Organisations also need to be mindful of the true potential for motion sickness amongst participants. In addition to utilising design techniques to minimise this potential, organisations also need to ensure mechanisms are in place to address this situation if it occurs.

RECOMMENDATION 2.

It is recommended that AMPC consider commissioning the development of “guidelines”, building on the findings of this project, to assist its members in determining appropriate use and considerations in engaging MR technology for training purposes.

7.1.3 Industry growth and maturity

Whilst the MR technology industry is relatively immature with regards to application in a training context, it continues to expand at a rapid rate, making it difficult to stay abreast of the latest developments and application.

Organisations need to tread carefully and seek assistance from trusted professionals to help navigate this complex and ever-changing environment.

Such professionals need to represent not just technology from a developer perspective, but also expertise in terms of instructional design in a virtual realm.

RECOMMENDATION 3.

It is recommended that individual organisations within the red meat industry ensure they have access to sufficient technical expertise when pursuing MR technology for training.

RECOMMENDATION 4.

It is also recommended that AMPC consider sourcing and appointing a “panel” of professionals that across the various areas of expertise required for MR training (e.g. developers, instructional designers, platform providers) and make the details of this panel available to its members.

7.1.4 Internal collaboration

MR technology is a cost-effective training mechanism if delivered at scale. To maximise cost-effectiveness, organisations should look to adopt an internally collaborative approach that incorporates key stakeholders such as the training department, IT department, procurement and other stakeholders,

MR technology efforts should be coordinated centrally to ensure compatibility of hardware and platform choices. An integrated approach will minimise duplication of efforts, reduce errors and enable achievement of economies of scale.

RECOMMENDATION 5.

It is recommended that organisations take an internally collaborative approach to adopting MR technology to enable realisation of cost benefits.

7.1.5 Foundational frameworks

This project has found there is a significant lack of foundational frameworks to guide the development of training materials for use in a MR environment.

Such frameworks are required to guide effective development and utilisation of available technologies, ensuring design is focused on learning outcomes and not dominated by the technology itself.

Examples of potential foundational frameworks include:

- Applicability of technology for training purposes (as per 7.1.2)
- Instructional design considerations (e.g. from instructional design methodologies to suggested design inclusions such as multi-modal cues)
- Evaluation frameworks and approaches

RECOMMENDATION 6.

It is recommended that AMPC consider commissioning the design of "guidelines" (further to Recommendation 2) to provide the foundational tools necessary to guide effective instructional design and evaluation of MR technology training materials.

7.1.6 Procedural significance

Any training program is only as good as the content it is designed to deliver. The significance of clear and accurate procedures on which training materials can be based has been a key learning of this project - if procedures are not fully accepted by learning participants, it severely distracts from the overall training experience.

In addition to clarity of procedures to form the basis of training, consideration needs to be given to how instructions may need to be adapted to suit the training delivery mechanism.

Delivery of training in a MR environment is different to training in a traditional context. Effective utilisation of MR technology in training often requires very specific and quantifiable instructions. For example, turning the valve in a clockwise direction is often not sufficient in a MR context – there is a need to explain to what extent the valve needs to be turned (e.g. until fully tightened, to 180 degrees, etc) to enable accurate visual representation of requirements.

RECOMMENDATION 7.

It is recommended that organisations focus on clarity and acceptance of work procedures prior to commencing development of MR technology-based training. In addition, it's recommended that consideration be given to the degree of procedural information required. Engagement of capable professionals in this space will help with this process.

7.1.7 New skills sets

With the anticipated uptake of MR technology training in a workplace context, organisations need new skills, or at least access to new skills, to design and deliver required content.

As outlined earlier, effective MR training is dependent on clarity of procedures that training will be based on, appropriate instructional design techniques and suitable technical design approaches to deliver seamless immersive experiences with minimal distractions.

This requires new skills sets within organisations. Skills that are based on utilisation of immersive training techniques. The required skill set is unlikely to remain static and is likely to reflect the changing nature of the industry itself.

RECOMMENDATION 8.

It is recommended that AMPC commission a program of work that identifies skills requirements for organisations to effectively deliver MR technology training. It is also recommended that this program of work be reviewed and updated on an annual basis for the foreseeable future.

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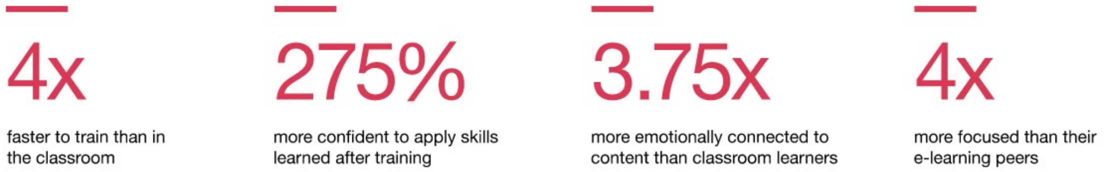
9 Appendices

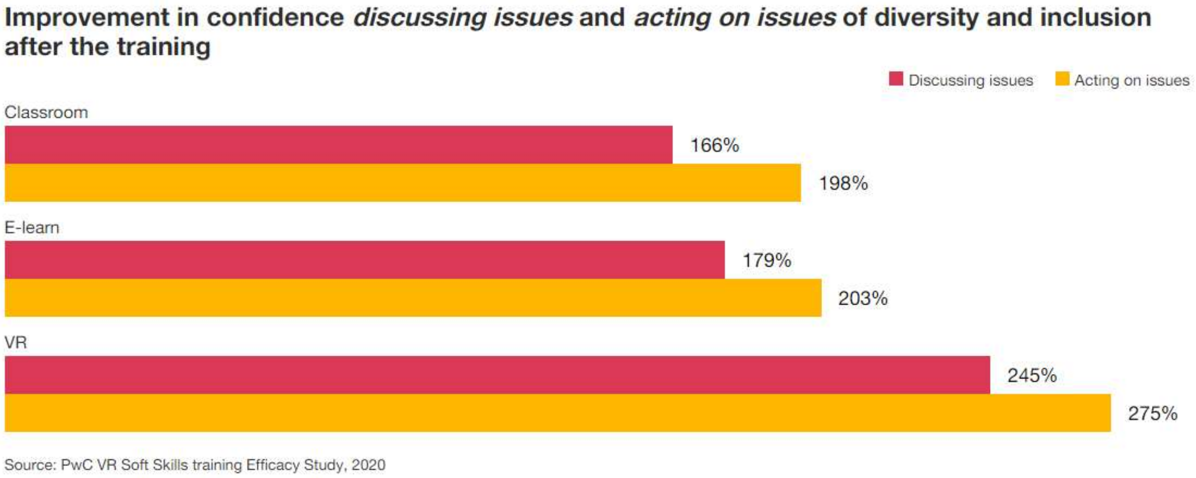
2.1 Appendix 1: Literature Review

1. Higgins, V. (2021). *Workers Rejoice: VR is Turning Industrial Training on its Head*. Forbes Magazine. [online] Available at: www.forbes.com/sites/honeywell/2021/01/19/workers-rejoice-vr-is-turning-industrial-training-on-its-head/?sh=3443afbb577c
Workers Rejoice: VR is Turning Industrial Training on its Head, by Vincent Higgins, talks to the positive impact VR is having on workers, particularly in industrial settings, noting that, beyond being transported to new environments, VR can also teach new skills and help people advance their careers. With the startling rate of technological change (e.g. AI, machine learning), Higgins proposes industrial workers have a choice – to surrender their jobs to technology or leverage said technology to make themselves more valuable, more productive and more relevant. Referencing a 2020 PwC study comparing different training modalities, Higgins notes that compared to classroom students and e-learners, VR learners learned faster, were more focused, were more emotionally connected to the course content and were more confident in applying the skills they learned after training. The promise of VR in the industrial workplace – by replacing analogue training with VR, organisations can create a workforce that "is not only more skilful and more knowledgeable, but also more productive, more engaged and, ultimately, more satisfied". Higgins challenges organisations to not ask merely what virtual reality can do (i.e. what cool experiences it can create), but also what it can achieve (i.e. what business problems can it solve), going on to outline the three most promising use cases for VR in training: • **Human Resources**: Higgins outlines how VR can help attract younger employees because they're "digital natives" as well as effectively capture, catalogue and transfer retiring workers' knowledge in a more interesting and accessible way. • **Safety**: Referring to the concept of digital twins, Higgins talks to the ability to use VR to safely undertake training in an environment that would be dangerous and inaccessible in the real world. • **Operations**: Again, Higgins refers to the use of digital twins in VR to access training, such as complex maintenance tasks, on the job, saving valuable downtime and minimising delays in production. Finally, Higgins talks to the future of 5G connectivity and next-generation reality capture for even more powerful advantages into the future.
2. Likens, S. and Eckert, D.L. (2021), *How virtual reality is redefining soft skills training.* PwC. [online] Available at: www.pwc.com/us/en/tech-effect/emerging-tech/virtual-reality-study.html?utm_campaign=sbpwc&utm_medium=site&utm_source=articletext
How virtual reality is redefining soft skills training talks to the VR advantage of remote accessibility during a time when employers need their workforce to learn new skills, particularly soft skills like leadership and resilience. Likens and Eckert highlight the ability for VR training to "offer an affordable way to upskill employees faster and with better results". In this article, noting that VR is already known to be effective for teaching hard skills and for job simulations, Likens and Eckert summarise the results of a 2020 PwC study of VR designed for soft skills training. The study took a group of new managers in 12 US locations and had them complete the same training – designed to address inclusive leadership – in one of three learning modalities: classroom, e-learn and v-learn (VR). The results of the study showed that VR can help business leaders upskill their employees faster and more effectively with VR learners:

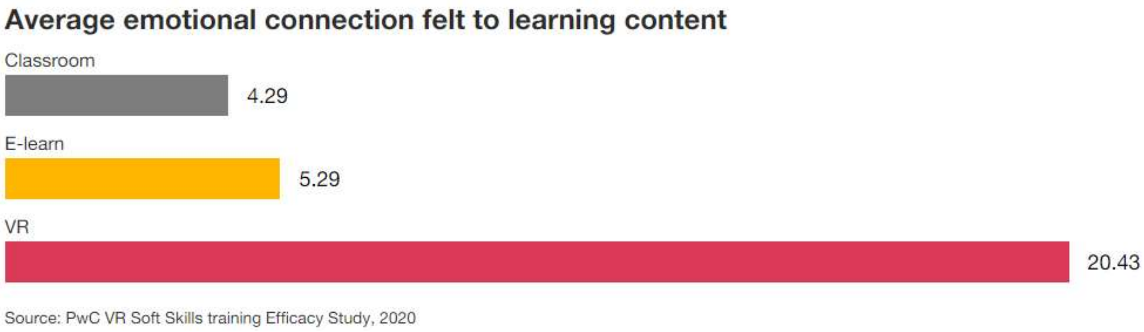


Likens and Eckert go on to summarise five top findings about the value of VR in soft skills training:

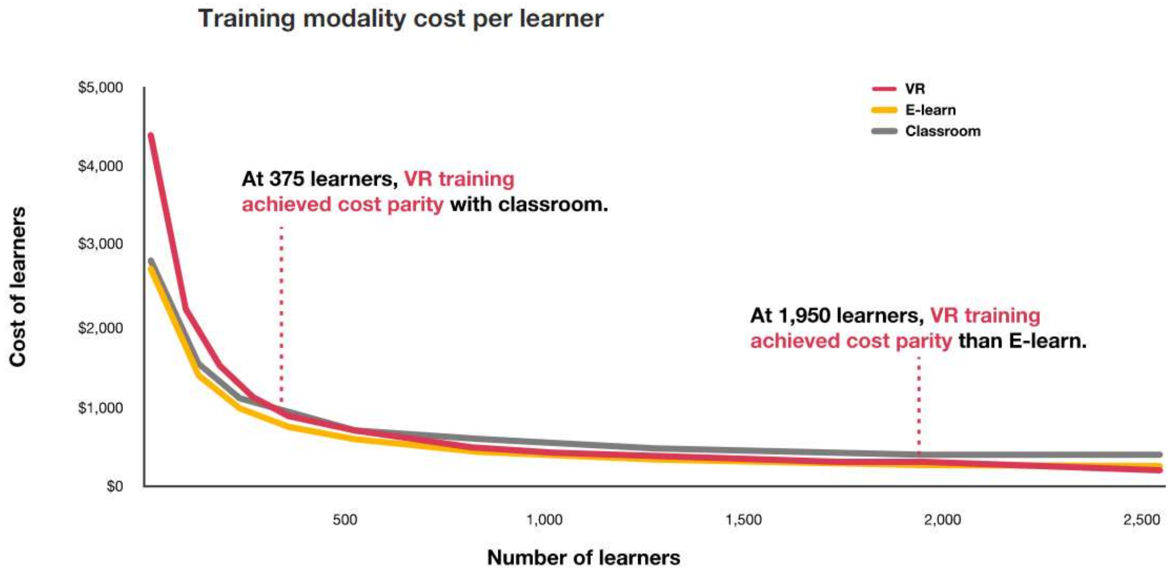
1. **Employees in VR courses can be trained up to four times faster**: What took two hours to learn in the classroom took only 30 minutes using VR. When accounting for extra time needed for first-time learners to familiarise with hardware, software, etc, V-learners were still three times faster than classroom learners.
2. **VR learners are more confident in applying what they're taught:** Because VR provides the ability to practice soft skills (such as giving difficult feedback) in a safe, low-stress environment, VR-based training resulted in higher confidence levels and an improved ability to actually apply the learning on the job with learners up to 275% more confident.



3. **Employees are more emotionally connected to VR content:** As people connect, understand and remember more deeply when emotions are involved, VR learning was found to be significantly more effective with V-leaners feeling 3.75 times more emotionally connected to the content than classroom learners.



4. **VR learners are more focused:** VR learners are significantly less distracted with headset-facilitated simulations and immersive experiences commanding the individual's vision and attention. As a result, VR trained employees were up to four time more focused than e-learning peers.
5. **VR learning can be more cost effective at scale:** Costs associated with hardware etc have reduced dramatically with enterprise headset ecosystems also able to be used like any other enterprise mobile device across multiple learners repeatedly to deliver training. The study found that, when delivered to enough learners, VR training is estimated to be more cost-effective at scale than classroom or e-learning. However, because VR content initially requires up to 48% greater investment, it's essential to have enough learners to make it viable. At 375 learners, VR training achieved cost parity with classroom learning. At 1950 learners, VR training achieved cost parity with e-learn.



Source: PwC VR Soft Skills Training Efficacy Study, 2020

Likens and Eckert note that VR will not replace classroom or e-learn training any time soon, but that it should be a part of most companies' blended learning curriculum. VR learning differentiates itself by combining the elements of a well-planned BXT (business experience technology) experience: business expertise to tackle challenges, a human-centred experience and the right technology to boost productivity with sacrificing quality.

Likens and Eckert recommend that ideally V-learners would debrief with other people who have completed the same VR training to determine how they can apply the learned skills in their jobs.

Finally, the article reiterates the value of VR enabling learners to practice skills that help them relate to diverse perspectives in the real world, with reference to a PwC VR soft skills course that enables executives and staff to practice new sales approaches. Learners get to make a pitch to a virtual CEO, but if they rely on business-as-usual sales techniques, the virtual CEO asks them to leave. However, if learners apply skills that demonstrate how they can bring value to the CEO's company, they get a "virtual contract" at the end of the conversation.

3. Allcoat, D., Hatchard, T. and Azmat, F. (2021). *Education in the Digital Age: Learning Experience in Virtual and Mixed Realities.* Journal of Educational Computing Research. [online] Available at: www.journals.sagepub.com/doi/full/10.1177/0735633120985120

This paper presents findings from a study examining the effectiveness of VR technologies for use in education, finding that whilst VR and MR resulted in similar levels of performance to traditional learning, both technologies presented higher levels of engagement, with higher levels of positive emotions in the VR condition. Further, the paper reported no simulator sickness with either headset used with both scoring similarly for usability and user acceptance. VR, however, did produce a higher sense of presence than MR. The paper notes that, overall, findings suggest that "some benefits can be gained from using Virtual and Mixed Realities for education".

The authors note that VR tech is only recently commonly accessible, however sales of the two most popular VR headsets (Oculus Rift and HTC Vive) are already estimated in the millions.

Anticipated findings

The paper highlights a 2018 study by Allocat and von Muhlenen that found VR had improve learning, higher engagement and more positive emotions (which are more conducive to learning) than traditional learning methods. Reference is then made to constructivist learning theory that views learning as an active process, whereby learners construct knowledge for themselves (as opposed to passively receiving information).

Through the higher engagement and positive emotions found in VR, and the lens of constructivist theory, the authors conclude that "thus VR and Mr, which enable active learning, allow one to experience and test such learner-generated hypotheses, which may be more effective compared to traditional passive learning methods".

Although active learning via XR provides a variety of benefits, the paper notes that costs and benefits vary between technology as does user acceptance and experience, suggesting "some participants may feel more vulnerable in a simulated reality world" because they are unable to see their real-world surroundings.

Evaluation mechanisms

- Perceived Quality Scale (Pribeanu et al, 2017), specifically developed for the evaluation of AR-based learning applications, consists of 18 questions which measure participants' perceptions of the quality of the learning materials on a five-point scale. Quality further split into three different sub-scales: ergonomic quality (perceived learnability and easy of use), learning quality (perceived efficiency and usefulness), and hedonic quality (cognitive absorption and perceived enjoyment).
- System Usability Scale (Brooke, 1996) consists of ten questions which measure the usability of the learning environment on a five-point scale. Example questions include: "I found the system unnecessarily complex" and "I felt very confident using the system".
- The Unified Theory of Acceptance and Usage of Technology Questionnaire (Venkatesh et al. 2003, Akbar, 2013) – used to measure user acceptance and comfort with being in a 3D simulated environment.
- Sense of presence was measured with the Igroup Presence Questionnaire (Schubert et al, 2001) – a scale with 14 questions (e.g. "I felt present in the virtual space") rated on a seven point scale.

Results

- Knowledge Test: Showed a trend for more learning in the VR condition, and less in the MR condition, but not at significant levels. Amount of learning did not depend on prior computer skills, gaming skills or amount of previous headset experience.
- Emotional and physical experience: Increase in elatedness in the VR condition, but a decrease in the MR and the traditional conditions. Increase in surprise in VR and MR, but not in traditional conditions. Pre and post test scores for simulator sickness were low.
- Learning experience: Post tests showed VR and MR groups reported being significantly more engaged than the traditional group – similar patterns for design and learning, but not significantly.

The main aim of this study was to "determine if VR or MR are suitable alternatives to traditional learning methods if they have any costs or benefits". The study found no reliable evidence to suggest VR and MR provide increased learning over traditional methods.

However, it was noted that participants had little opportunity to familiarise with the equipment – individuals with the VR and MR groups were able "to learn to use new equipment, acclimatise to a simulated 3D environment, and learn as much from the material" as traditional learning. The study notes that this suggests that learning could potentially be improved with MR and VR than traditional learning if users are familiar with the equipment.

The study also noted the emotional benefit of learning in VR for surprise and elatedness, which is good for student satisfaction as consumers. VR and MR were both found to be better than traditional learning on engagement.

The authors identified simulator sickness as a potential problem, although it was not the case with this study, referring to the need for limited use/ short sessions and design targeted at reducing motion sickness.

Finally, the paper provides direction for future research, suggesting it should "consider longer durations, as well as longitudinal impacts of the use of this technology. One hypothesis would be that over time the novelty effect of using the equipment would wear off, and the benefits would decrease. On the other hand, the benefits might increase over time as individuals become more familiar with technology and how to use it. As individuals become more proficient with the equipment, they may find the novelty less distracting and be more able to focus on the learning. Therefore, research considering the long-term effects of the technology is an important future focus."

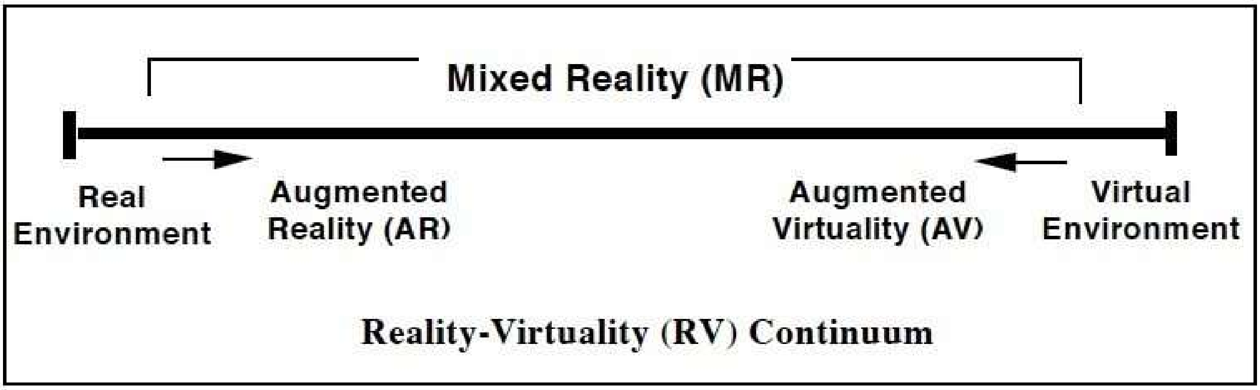
4. Vasarainen, M., Paavola, S., Vetoshkina, L. (2021). *A Systematic Literature Review on Extended Reality: Virtual, Augmented and Mixed Reality in Working Life*. International Journal of Virtual Reality. Vol. 21 No.2 [online] Available at: www.ijvr.eu/article/view/4620

The paper reviewed research on application areas and collaborative uses of XR in real-life work settings. The authors analysed the application areas as well as the added value and limitations of XR technology in practice.

A key finding of the review is that there are still few cases of actual long-term use of XR technologies. Design, remote collaboration, and training came forward as the main application areas. XR as a medium was identified as having potential to overcome obstacles set by time and space, safety and resources, especially aiding work requiring shared spatial experiences. However, the authors found that XR applications are case dependent, and did not find yet any easily applicable technology that would not require special technical expertise on the matter.

The paper found that XR solutions are not universal and should be considered on a case by case basis. For example, there were social, technological, situational and practical needs in team training differing from individual training scenarios.

Referring to Milgram and Kishino's (1994) virtuality continuum (below), the authors noted the differing definitions of XR and its components by various authors, fuelled by the continuous advancement and new applications of technology. The lack of established definitions of key features, such as immersion and interaction, led the authors to concur that XR is still "technology in the making".



The paper noted that whilst XR provides varying degrees of immersion, headset use does not automatically guarantee learning, but rather enables access to "situations that are either inaccessible (in time or space) or problematic (dangerous or unethical)". Referring to 2018 studies, it is suggested that "future research on VR headsets be concentrated on "how and for what" the technology should be used, since it is only a matter of time for it to be vastly applied".

Regardless of XR form, the paper noted there are different levels of immersion and interaction, either with the virtual world and its contents or between participants. Headsets were widely used but equally desktop and screen-based solutions were common: occasionally, the most straightforward and simple technological solutions were the most workable. The authors noted that "in a way, we may consider the most powerful technology to be the one that does not draw too much attention towards itself".

The paper noted three different research areas with XR: collaboration, evaluation of knowledge transfer, and work practices and that within those areas, theories on collaboration, social interaction and practices were common. Expecting to see novel ways of collecting research such as the use of a united screen and recordings of virtual content), the authors found applied research methods to be primarily traditional, incorporating interviews, questionnaires and observations.

5. Accenture. (2021). *Immersive Learning with XR*. [online] Available at: www.accenture.com/_acnmedia/PDF-164/Accenture-Immersive-learning.pdf#zoom=40

Between February and March 2021, Accenture Research conducted a global survey of 306 senior executives in five countries (China, France, Germany, United Kingdom and United States) to understand their organization's investment in and use of extended reality technologies for workplace training. Respondents represented more than 12 industries from companies $1 billion or more in global revenue. *Immersive Learning with XR* provides an overview and commentary on survey findings.

The report starts with a "reality check" – citing that the pandemic has changed what workers want and that employers now need to create "a better normal", taking the technology lifeline that kept people connected and extending it to today's needs. The report highlights the need for "new ways to develop essential skillsets, provide proper diversity training and enable people to learn when and how they want".

The report outlines the business case and strategy for "how to go beyond and create an enterprise-wide immersive learning rollout powered by XR technology", stating that organisations that succeed in reengaging fully with employees will be those that go beyond one-way training experiences associated with classroom or online environments to engage all the human senses, "bringing novelty and excitement to collaborative situations, and offering interactive and immersive learning opportunities".

Citing "immersive learning provides exciting and impactful ways to engage and upskill/ new-skill employees through realistic, safe and personalised experiences that are affordable at scale", the report points to the dependency on the right scope, scale and agility – as well as dependency on effective relationships between Chief HR Officer and the Chief Technology/ Information Officer to realise this opportunity.

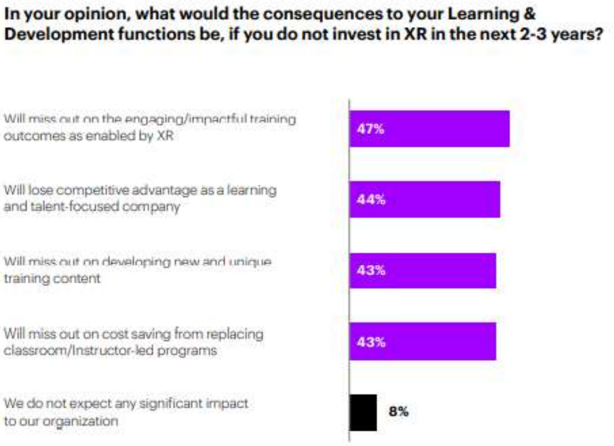
Referring to the global skills shortage, the report notes that "the imperative of this new reality cannot be ignored: Companies must increase their investments in employee L&D just to remain competitive in the market. Moreover, they must find innovative ways to keep employees engaged – or risk losing them."

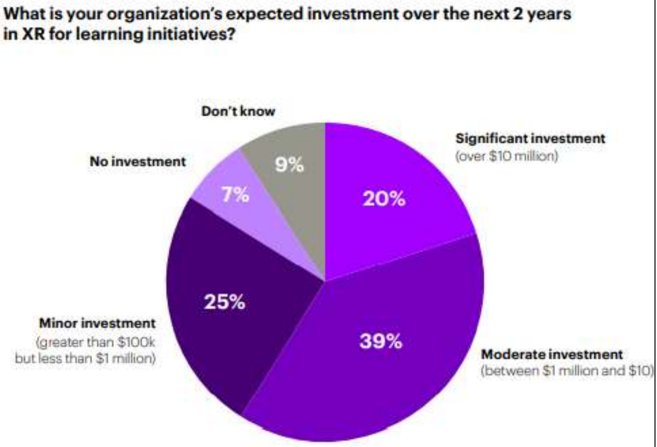
XR learning experiences can play a vital role in addressing these challenges but must be considered in their approach - one-size fits all employee development programs can fail to accommodate the variety of learning styles or personalise agendas for workers.

The article points to deficiencies in basic learning retention and the need to invest in more innovative, effective and affordable mechanisms for training - 90% of respondents to the Accenture Immersive Learning Survey said their existing training methods needed to be more effective and efficient. To address these limitations, Accenture encourage companies to reinvent their L&D programs and innovate with XR technologies to engage workers more deeply in the learning process.

The Accenture survey highlighted the intention of organisations to significantly increase spend on XR L&D into the future, citing significant impacts to their business if they do not do so.

> "Where most companies go wrong is when they map behaviors generically to roles. Learning must be where you are, not where everyone else is. Learning must be contextual for it to stick. Companies need to shift away from 'one and done' personality tests. They are helpful in terms of insight, but not in terms of your ability to grow and shift."
>
> Sallyann Della Casa, Founder of GLEAC, a learning analytics company

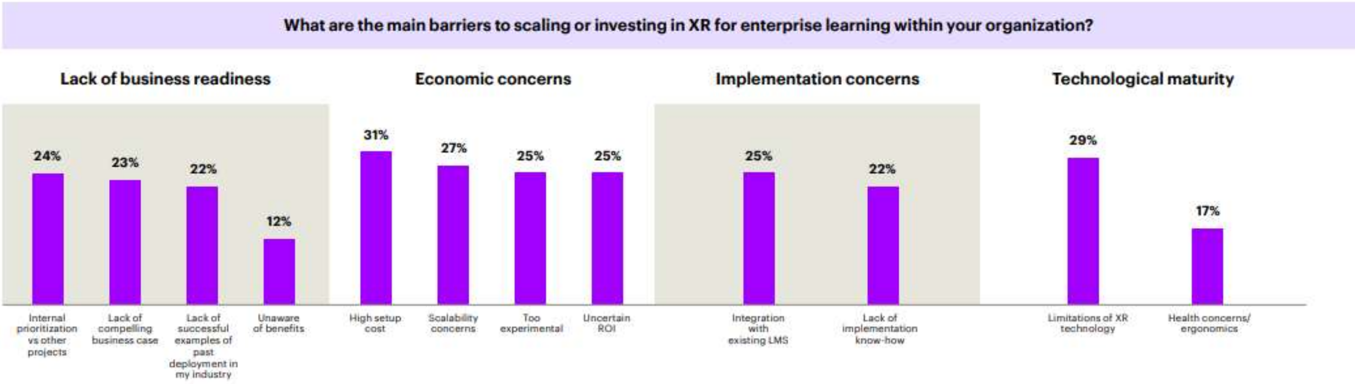




The article talks to the effectiveness of immersive learning in retention and recall, noting these solutions also offer a risk-free training environment for in-the-field scenarios, including hazardous situations, and humanize remote collaboration by enabling sensory experiences and life-like instincts. They also create an effective setting for simulated human interactions, helping to enhance people skills such as communication and empathy.

The article refers to the ability for immersive learning, through XR, to contribute to a continuous learning culture, "helping employees confidently prepare for roles while on the job and providing instant feedback in a virtual, collaborative space". The ability for learners to take lessons independently or in groups and repeat lessons until they "achieve mastery" is also noted, as the ability to obtain real-time data about employee actions and behaviours through biometrics incorporated in XR offerings.

Despite these benefits, the survey points to a range of barriers to scaling or investing in XR, as outlined in the diagram below.



Accenture outlines a program where employers can overcome these barriers through:

- **Scope**: Companies must broaden the scope of XR learning from one-off employee training to the entire employee experience, including expanding the use of the headset to modernise employee experiences such as onboarding, recruiting and collaborative events.
- **Scale**: Good data capture, analysis and feedback from learners provides companies with the flexibility to amend strategies and training designs quickly. This information should be used to learn, improve and broaden implementation of XR programs.
- **Agility**: Companies need to adopt an agile technology suite as part of its' technology architecture to support XR capabilities and cites the need to establish a mobile device management (MDM) platform to manage and onboard XR devices more easily.

The report recommends organisations develop a vision and strategy for XR incorporating and consider:

- **Infrastructure:** "Enterprises should build a relationship between the devices (located at the edge of the network) with cloud computing to drive agility and flexibility… using the cloud as a centralised scalable platform to generate insights from data and the edge devices for managing real-time, pre-defined content".
- **Hardware:** Organisations should broaden the scope of IT strategies to incorporate XR devices. MDM platforms will continue to evolve with choice being important for both existing functionality and future opportunities. Employees should be given access to both public and enterprise apps to increase engagement. Organisations should consider an XR centre of excellence and device management policies to facilitate procurement and reduce capital risk.
- **Ecosystem**: Organisations should collaborate with a digital transformation expert and other learning ecosystem players focusing on organisational development.
- **People:** Finally, the report talks to responsible XR in managing data privacy and building transparency and trust with employees by "designing solutions and using ethical practices… infusing company culture and social opportunities into the experience will help engage employees and appeal to the future workforce".

In terms of engagement, the report notes an XR offering takes more than adding tools to existing workflows and recommends partnering with experts as "immersive learning and XR technology provide unique experiences that require a deep understanding of specific requirements and best practices". It's recommended that organisations "look for a partner with a unique combination of business and technology experience mixed with industry and functional experience".

6. Yang, K., Zhou, X., Radu, I. (2020). *XR-Ed Framework: Designing Instruction-driven and Learner-centred Extended Reality Systems for Education.* [online]. Available at: www. arxiv.org/pdf/2010.13779.pdf

This paper talks to the lack of a clear framework to understand different design dimensions in educational XR systems and seeks to address this gap through a literature review of 70 papers to explore two questions:

a) When designing XR for education, what design dimensions should be considered by practitioners?
b) What instruction-centred design guidelines and procedures could practitioners follow when they design educational XR applications?

In response to this research, the authors developed an *XR-Ed framework*, revealing design space in six dimensions as well as development of *XR-Ins*, an instruction-oriented, step-by-step guideline in educational XR instruction design, providing design choices and design inspirations for practitioners.

The framework and process outlined in the paper is aimed at addressing the challenge that many XR practitioners may not be intimately familiar with educational theory and instructional design and to reducing the chances of XR design being "hit and miss, driven by intuition and common-sense explorations".

XR-Ed Framework

1. Spectrum of Physical Accessibility of Target Learning Content

Researchers found "turning the invisible visible" could trigger students' interests and curiosities in science as well as developing a connection between learning in classrooms and their lives. Subsequently, the paper argues for XR practitioners to consider XR's ability to simulate a normally inaccessible or unobservable process as this may offer a unique, novel learning

Fig. 1. The spectrum of D1: Physical Accessibility of Target Learning Content

experience to learners. Four typical scenarios that XR can afford learners to access that are normally inaccessible include:

a) Time inaccessibility: e.g. allowing learners to travel in time to experience different historical periods
b) Physical inaccessibility: e.g. exploring the solar system by freely moving around planets
c) Dangerous situation: e.g. providing training for firefighters in physically and psychologically stressful situation through simulation live firefighting; learning gorilla behaviours through interacting with a virtual gorilla or using MR to simulates earthquake to teach basic physics
d) Ethic problem: for example, allowing non-experts to perform surgery.

2. Spectrum of Formal Degree of Learning

Fig. 2. The spectrum of D2: Formal Degree of Learning Scenario

This spectrum looks at how formal the learning scenarios are with "formal learning" being pragmatic and organised and "informal learning" being more casual, unstructured, spontaneous and often unintentional. If informal learning comes consciously with a defined purpose, it becomes "non-formal".

- XR in formal learning often seeks to augment normal instruction with digital media content, such as augmenting instructions with real-time AR image depicting movements of sun-earth turntables to teach earth science.
- Non-formal learning – informal learning with a purpose. XR applications typically used to provide a gamified experience in an effort to better engage learners in a formal learning context. Three techniques were frequently adopted: storytelling, learning by making, role play or participatory simulation.
- Informal learning normally unplanned and self-directed occurring outside of a conventional setting. For example, using MR to build artwork that people can interact with, enjoy and explore in a museum context.

The paper notes that the difference between formal and informal learning is not always clear nor mutually exclusive, stating that if practitioners are trying to decide whether to choose formal or informal learning activities, besides considering technologies, several instruction-driven and learner-centred guiding questions could be helpful to consider, including:

1. Does the learning outcome need to be measurable?
2. How self-motivated are your target learners?
3. How capable are your learners of self-directed learning (which informal learning may require)?
4. What degree of gamification is appropriate for target learners and content knowledge?

3. Spectrum of Interaction with Virtual Agent

Fig. 3. The spectrum of D3: Social Interactivity

The third dimension of the framework concerns support for social interactivity, broadly defined as "the amount of communication learners have while engaging in the systems".

The paper notes that consideration should be given to the degree of social interactivity that is built into XR educational design – ranging from no interaction, interaction with virtual agent to interaction with other learners.

With reference to the degree of social interactivity, the paper cautions XR practitioners about the need to balance the risk of over-scripting or over-explaining, potential distract agents or other learners could bring that might interfere with learning tasks and to avoid extraneous information which may result in learners being overloaded.

4. Spectrum of Learner Agency

The fourth dimension asks what level of agency learners have – or the “power to act” and the degree of initiative of the learners.

Fig. 4. The spectrum of D4: Learner Agency

Low learner agency applications position learners as passive recipients of knowledge and incorporate activities such as reading, viewing or observing. High learner agency approaches would incorporate a more immersive experience that would potentially better engage learners in the learning process by seeking more learner input through role-playing, participatory simulatory etc.

The paper notes that while consideration needs to be given to the degree of learner agency, research shows that groups with higher control learned more content than the passively observing groups.

5. Spectrum of Virtuality Degree

This spectrum refers to how much virtuality designers can provide through a learning experience, noting that the virtuality degree can lead to different learning experiences.

Fig. 5. The spectrum of D5: Virtuality Degree

- Purely virtual environments are more immersive and engaging. In terms of design recommendations, research shows that contextually embedded instructions texts can lead to learners’ lower cognitive load and high self-efficacy. Audio is less cognitively demanding but text makes information more available.
- Physically-enhanced virtual environments incorporate content added for contextual learning by bridging the physical world and virtual world using items such as augmented reality. This can enable learners to physically interact with computational concepts. Compared to a purely virtual environment, involving physical objects enables tailoring learning environments in a more accessible and flexible way.
- Virtually enhanced physical environments refer to the amount of virtuality used and whether or not the main learning contents are presented physically or virtually. In virtually enhanced environments the main objects of learning content can be enhanced by virtually-presented cues that can reduce information overload, provide immediate feedback and provide in-learning support (e.g. toolkits). This approach can be particularly helpful for lower-level students or students with lower self-efficacy.

6. Spectrum of paper and pencil assessment

This spectrum refers to how seamlessly assessments are built into the system, such as:

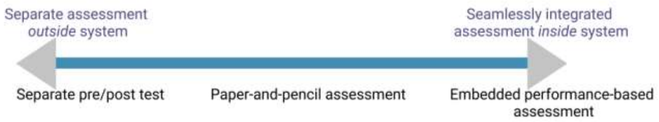


Fig. 6. The spectrum of D6: Assessment

a) Separate pre/ post test outside of the system
b) Paper and pencil assessment embedded in the system
c) Performance based assessment embedded in the system

The paper notes the majority of research related to XR learning has to date been based not on learning outcomes, but on system usability. The authors recommend that as the domain matures, there should be an increased focus on more thorough evaluation of actual learning through quantitative and qualitative methods.

XR-Ins – a Step-by-step Approach for Designing XR Instructional Activities

The paper provides a three-step approach for designing XR instructional activities, including what aspects of the XR-Ed Framework to consider at each stage and providing examples of relevant learning science theories, as outlined in the table below:

Step in XR-Ins Guideline	**Dimension to consider in XR-Ed Framework**	**Example Relevant Learning Sciences Theories**
Identify Learning Goal	D1 - Accessibility	Anchored learning
Assessment Design	D6 - Assessment	Exam Expectation Spacing Effect Goldilocks Principle
Instruction Activities Design	D2 - Scenario D3 - Social Interactivity D4 - Agency	Stories and Example Cases Coherence Principle

7. Winther, f. et al. (2020). *Design and Evaluation of a VR Training Simulation for Pump Maintenance Based on a Use Case at Grundfos*. [online]. Available at: www.researchgate.net/publication/341317338

VR training simulation for a use case at Grundfos, a Danish pump manufacturer, in which apprentices lean a sequential maintenance task.

Simulation evaluated in a user study with 36 participants, comparing it to two traditional forms of training (Pairwise Training and Video Training). The paper describes the VR scenario and discusses design considerations for VR simulation, and presents result of evaluation. The findings support that VR training is effective in teaching the procedure of a maintenance task. However, the study also found that traditional approaches with hands-on experience still lead to a significantly better outcome.

Traditional training at Grundfos is problematic for pump maintenance tasks: either a pump needs to be shut down and uninstalled from the system, an additional pump must be acquired and made explicitly available for training purposes, or novices can only train when ordinary maintenance tasks are scheduled.

A common evaluation task and evaluation criteria were defined, with evaluation based on:

- Completion time
- Number of errors
- Confidence in actions

Table 1: Sequence of steps that need to be carried out in order to replace the o-ring on the dosing pump.

No.	Disassembly of dosing pump	No.	Assembly of dosing pump
1.	Wear gloves and safety glasses	11.	Attach the new O-ring to the drainer
2.	Depressurize dosing pump	12.	Attach the drainer to the dosing pump
3.	Dismantle top and bottom ball valves	13.	Fasten the diaphragm
4.	Detach the back-lid	14.	Close diaphragm digitally
5.	Loosen the screws in the dosing head	15.	Mount the dosing head
6.	Take off the dosing head	16.	Attach each of the four screws
7.	Open diaphragm digitally	17.	Fasten the screws crosswise
8.	Loosen the diaphragm	18.	Attach the back lid
9.	Remove the drainer	19.	Attach bottom and top valve
10.	Remove the old O-ring		

The VR Training simulation was developed in Unity 3D2 and experienced through an HTC Vive3 HMD. Matching HTC Vive controllers served as input devices for interaction in the virtual environment. The training simulation was run on a Windows PC with a GeForce GTX 1070 Graphics Card.

Subject matter experts assisted in outlining the individual steps of the maintenance task and the identification of evaluation criteria. Further, they supplied information on the specific procedure of traditional training methods and the types of skills that were to be acquired. Additional design decisions were made in consideration of central Human Computer Interaction (HCI) principles, such as supporting direct manipulation and multimodal guidance.

In the resulting prototype, the user interacts through two virtual hands (3D hand models that appear to be wearing white gloves) which following the movements of the Vive controllers.

The program incorporated a special scene prior to the actual training to enable learners to become familiar with the technology. The scene included a workbench and a range of objects that the users could playfully acquire to acquire skills for manipulation.

During the training a guidance system provides multimodal cues, including voice recordings, textual instructions, highlights and animations. To improve knowledge transfer, two levels of difficulty were implemented: beginner and intermediate.

<u>Findings</u>

- *Completion time:* On average, participants took about 1.6 times longer for the maintenance task after VR training, compared to both other groups.
- *Number of errors*: The VR training group made more than three errors on average, while both other groups made about one.
- *Confidence in actions*: Pairwise training and video training generally led to higher confidence than VR training.

The paper provides a summary of common types of errors, such as orientation, sequential and safety errors. During the VR training, multiple challenges were observed regarding the interaction techniques and in regard to remembering the sequence of events.

In summary, the hypothesis that participants trained in VR would be capable of performance a maintenance task on a real-world dosing pump was supported – all VR training group participants were capable of completing the maintenance task after just 20 minutes of training. This finding is considerable given the challenges of traditional training methods and the scalability of the VR training setup.

The authors note that the success of the medium is arguably task-dependent with a need to explore what kind of skill acquisition is best supported by VR training.

Based on the opinion of training experts, the authors expected VR training to compare similarly with other training methods in terms of task completion time and number of errors - this hypothesis was not supported. These findings are consistent with quoted research which shows that when performing a cognitive manual task within a VE, manipulating physical objects results in significantly improved performance, compared to manipulating virtual objects.

The paper suggests that results point to supporting training with AR could be superior to a VR simulation, since this allows the combination of hands-on experience on the physical machine with digital assistance through animations and step-by-step instructions. However, the additional requirements of AR are noted, such as reliable tracking of relevant physical components. Furthermore, AR relies on the availability of the physical machine, components and tools, and the ability to stage the scenario that should be trained, which may incur additional costs, difficulties and safety concerns.

Hence, the authors conclude that VR remains a compelling option, not least due to its purely artificial nature, which enables training of otherwise impossible scenarios, e.g., including products that do not yet exist.

8. Xie, B. et al. (2021) *A Review on Virtual Reality Skill Training Applications*. Frontiers in Virtual Reality. [online] Available at: www.frontiersin.org/articles/10.3389/frvir.2021.645153/full

Xie et al provide an overview of currently technology and approaches in VR training, the domains in which VR training is being applied. The paper also provides an overview of the common assessment tests and evaluation methods currently used to validate VR training effectiveness before pointing to likely future directions of the technology.

The paper talks to a “pipeline” creation process comprising task analysis, training scenario sketching and implementation. In the implementation phase, Xie et al outline the need to consider software/ development tools, procedural generation techniques and hardware options.

In terms of domains of use, Xie et al review the challenges and approaches of employing VR training in different domains, including first responder training, medical training, military training, transportation, workforce training and interpersonal skills training.

In terms of workforce training, Xie et al report “It is critical for a training session to faithfully mimic a real working environment and possible challenges that a worker may face in the workplace. Compared to a traditional training environment, virtual reality provides a low-cost and replicable training to satisfy such needs while offering a mistake-tolerant environment to relieve stress that a new worker may have.”

Xie et al note that both employees and employers could benefit from workplace VR training. “On one hand, new workers can familiarize themselves with the workplace environment and operation through replicable, mistake-tolerant VR training. Employers can use the training results to evaluate whether their employees are ready to work in the field. With a headset, as well as a few motion capture sensors and motion trackers, workplace VR training research has mainly focused on two aspects: 1) improving workers’ skill in performing machinery and equipment operations (e.g., work-at-height training), 2) raising workers’ awareness at work by providing safety and risk assessment training for high-risk occupation (e.g., hazard inspection at a construction site).”

Xie et al report that, aside from training highly specialised technical skills, VR has recently shown promise for interpersonal skills training, noting that "as VR hardware and software improve, the potential for rich interactions among people—a crucial factor for interpersonal skills development—becomes more likely, especially due to the psychological experience of being there".

The paper points to emerging technologies, such as haptic interfaces, that are being combined with VR training, to support workplace training.

In terms of measurement, Xie et al find that "the most commonly used method is the quantitative method in general" and the pre and post test experiment design in particular where measurement is recorded prior to and after training. These methods of evaluation typically incorporate a questionnaire.

As a newly establish form of research, biometrics is defined as "the use of distinctive, measurable and physical characteristics to describe individuals". Psychophysiological measures incorporate:

- Eye tracking
- Facial expression analysis
- Skin response (GSR)
- Hear rate variability (HRV)

GSR HRV and eye-tracking are the most widely used biometric indices because of their ability to predict the affective state of the subject. Inclusion of biometric measurements in VR training helps researchers collect and analyse the emotional feedback of the trainees, broadening researchers' understand of VR experiences in addition to traditional evaluation approaches.

Qualitative training evaluation is also common, helping trainers to understand user experiences with VR training as a tool. This can be useful in determining effectiveness of training.

However, Xie et al note conflicting opinions about whether user experience is a relevant factor in transfer of knowledge, with researchers suggesting that "the factors relating to trainee characteristics (cognitive ability, self-efficacy, motivation and perceived utility of training), training design (behavioural modeling,error management and realistic training environments) and work environment (transfer climate, support, opportunity to perform and follow-up) are the ones "that have exhibited the strongest, most consistent relationships with transfer of training.

Reference is made to the importance of focusing on the content in any training effort, reinforcing it is important to train people on the exact areas/ topics needed for people to learn.

Finally, the paper talks to the likely future of technology and devices associated with VR training, noting significant efforts in the areas of haptic feedback and improving immersiveness, such as through scents and thermal feedback.

Networked VR enabling multiple users to perform training simultaneously in a shared virtual space is referred to, as is the potential benefits of the fifth-generation (5G) network and cloud computing, making it possible for people to use VR without an expensive local setup

Multi-user training, such as enabling first responders to work as a team, and AR based training are also areas likely to see increasing focus into the future.

2.2 Appendix 2 – Draft Evaluation Survey for MR Tech Training

Mixed Reality Technology Training - Evaluation Survey

1 = strongly disagree/ 5 = strongly agree

QUESTIONS			1	2	3	4	5
Attitude toward using	Q1	I was anxious before using the VR/AR technology					
	Q2	I enjoyed using the VR/AR technology					
	Q3	Training with VR/AR was more engaging than conventional training methods					
Perceived ease of use	Q4	I found the technology easy to use					
	Q5	I think most people would be able to use the technology					
Perceived usefulness	Q6	The technology provided me with a good understanding of the real environment					
	Q7	The technology helped learning to be more focused					
	Q8	I am more likely to remember what I learned through using the VR/AR training than via traditional training methods					
	Q9	I feel the training provides me with the majority of things (approximately 80%) I need to know to undertake the task					
	Q10	If I had the option, I would be more likely to use the technology to access refresher training than to ask my supervisor or subject matter expert for assistance					
Intention to use	Q11	I wish this technology was used for training more widely					
	Q12	I would recommend using the technology for training of other similar tasks					
	Q13	If required to undertake training in a similar task in the future, I would like to be able to use VR/ AR technology					
General	Q14	Without the VR/ AR training, how would you currently go about learning this task?	Open text response				