IMMERSIVE TECHNOLOGIES IN AEROSPACE TRAINING

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Contents

*Data tables available as a separate appendix.

Executive Summary

Financial support from the Ontario Ministry of Labour, Training & Skills Development (MLTSD) Skills Development Fund (SDF) was secured by the Ontario Aerospace Council (OAC) to enhance their Competencies Online Advancement Skills and Training (COAST) program. OAC in partnership with Downsview Aerospace Innovation & Research (DAIR) sought to develop extended reality (XR) content to be included in a newly developed technical COAST program. This new technical Composite Technician training program was targeted for upskilling of existing employees and instilling and attesting to the skills and competencies of a Composite Technician.

In addition to providing required upskilling to trainees at key Ontario companies, the project posed a research question to be investigated – **Does integrating immersive technologies enhance aerospace technical training and lead to better learning outcomes?**

A. What Do We Know Now That We Didn't Before?

Those who had access to Virtual Reality (VR, one example of XR) experiences in the COAST Composite Technician Training program valued its inclusion as part of the training because:

- It allowed for opportunities for **repetition and learning from mistakes**.
- VR created **less stressful training environments** where individuals could recover from errors without harm or waste.
- They valued the VR experience as **fun and interesting**.

As part of the research, key informants shared that there is a disconnect between current pre-service training (college and university training) in Canada and aerospace industry needs. They suggested that XR could be harnessed to:

- **Attract young workers** to the sector, which is a key concern for the aerospace industry.
- **Update and improve pre-service training and in-service training** in a way that is more beneficial and cost effective.
- **Harness the knowledge of an aging workforce** who will be leaving the aerospace sector.

Key informants, as well as some evidence synthesis sources, outlined challenges to the inclusion of XR in aerospace technical training. However, some of these might be mitigated by time. XR technologies are evolving quickly, meaning that some of the issues discussed in this report could change in future:

- **Cost:** The cost of equipment (VR headsets, etc.), which currently could be a barrier to inclusion, may be mitigated in future.
- **Economies of scale:** The future of XR may hold economies of scale, however it is too soon for there to be strong and credible evidence for this.
- **Hesitancy:** Time often brings with it a decrease in hesitancy of adoption of new technologies.

Key informant interviews provided context on XR, including what still needs to take place before widespread adoption.

"Interesting to see the early adopters and where it is used."

"Needs to be general enough to be applicable, but also realistic enough to the specific process."

"The value of a classroom is theory, while the value of a shop floor is hands on. It is critical to make any XR most like a shop floor…a real hands-on experience. So, you need things like touch and resistance."

B. COAST Composite Technician Training Program

Returning to the research question, the findings from exam scores in the course suggest the research question was not upheld in this case, namely that integrating two VR experiences into Module 11 of the Coast Composite Technician Training Program did not lead to better learning outcomes. This indicates that there is no discernable learning effect of integrating VR into this training course as it was executed in this instance.

Why might this be?

- **Low Dosage:** The intervention itself (the inclusion of VR experiences in Module 11) was too ‘low dosage.’
- **Assessments:** For this first year of the program, testing was based on participation and knowledge but there was not time for the assessments to be tested and/or piloted to ensure validity and reliability with respect to the key research question. Therefore, from the research perspective it is not possible to know if they measured what they intended to measure and if these measures are consistent across time and/or items – it is possible that the assessments were not granular enough to detect any difference in learning outcomes between the immersive and non-immersive groups.
- **Ceiling Effect:** Because a passing grade was 65%, this contributes to a ceiling effect. This may have affected the ability to show significant differences in aggregated scores by group.
- **Group Size:** Statistical significance is volatile to sample size, with small groups being less likely to detect a statistically significant difference.
- **Group Composition:** Some trainees were already working as composite technicians. It is possible that familiarity with the competencies required for the job may have influenced the results.
- **Technology:** It is possible that no significant difference in learning outcomes was detected because this technology is not sufficiently sophisticated to mimic the real-world realities of working on the composite shop floor to provide improved learning outcomes.

These considerations are important when creating technical training programs with XR in the future. By mitigating these concerns, the original research question of whether XR can directly lead to increased learning outcomes for the individual could be answered more definitively.

C. Moving Forward for Maximum Impact

Findings from this research provided technical training areas which would warrant serious consideration for inclusion of XR technology. These findings come from the evidence synthesis of the report and interviews with participants in the course and key informants. It also includes results from a review of the different types of currently available XR technology, including costs, immersiveness, scalability, and lead time in developing and executing a training pilot program.

This would be true for a company looking to implement XR into its own internal training, or an organization creating industry-wide content in an effort to provide training for multiple users.

There are areas of aerospace technical training where XR technology is likely sufficiently sophisticated and affordable today to create a quality learning experience. By focusing on these areas first, the opportunity exists for XR to evolve and offer a broader reach for training in the future.

In their words

Both program participants and key informants provided detail and commentary on where XR could provide benefits to aerospace technical training.

Increasing Awareness

"Awareness of the task and working environment."

"...between engineering and production... when we have technical difficulties, it can be difficult to communicate issues of production to designers/engineers"

"For the operators doing the steps before and after. VR would let them try it and better understand why things are done in a certain way."

Onboarding new hires

"It's a benefit to new people who have not had experience."

Orienting to general equipment

"Commonly used equipment... how to use a band saw, lathe and the manufacture of metal parts."

Improving tools

"It would be valuable for designers to get a sense of how the tools will actually be used."

1 Introduction

A. Overview

1. Program Genesis

In 2021, the OAC secured funds from MLTSD to expand the pre-existing COAST program and partner with DAIR to develop immersive content to be included in a newly developed technical program, which focused on the skills and competencies of a Composite Technician.

The innovative aspect of this program was the integration of virtual reality experiences (VR, a specific version of the broader term, extended reality (XR)) in the final tranche of the program. Specifically, in Module 11, the lamination process, a total of two 10- to 20-minute VR experiences were developed for the pre-preg[1] and VARTM[2] processes.

The COAST Composite Technician Program was delivered virtually with 13 self-paced learning modules over a period of 10 weeks. Each week, participants had an online learning session with a technical instructor to answer questions about that week's learning. The program was delivered in three tranches with online tests (for each module) and online exams (for each tranche).

To bring this project to fruition, the COAST learning production team (consisting of the Ontario Aerospace Council, LSM Consulting, and Shadowbox Learning Services) partnered with UP360 to undertake the design of the VR experiences. UP360 is a technology company which focuses on the use of VR for training, creating immersive content and real-world simulations.

DAIR, in partnership with the OAC, engaged Inquiry Minded Consulting Inc. (IMC) to design and undertake all aspects of the research process. IMC worked collaboratively to build processes that are authentic and resonate with all stakeholders. IMC brings together professionals involved in social research and impact assessment who have worked in the social sciences and education. In particular, IMC's professionals worked with Manitoba Aerospace on several projects while with another company, Proactive Information Services Inc., which has now sunsetted due to retirements.

Collectively, the goal of the research was to investigate the impact of integrating immersive technologies in aerospace technical training by using this newly developed Composite Technician Training Program as a pilot project. The basic research question was – Does integrating immersive technologies enhance aerospace technical training and lead to better learning outcomes? It is hoped that this research will provide a framework for further research into the benefits of XR for aerospace training and an understanding of the potential advantages for companies – whether in a classroom or on the shop floor.

2. Research Design

Collecting data in different ways, through multi-method design, provided a well-rounded and robust approach to the research. Wider measures such as questionnaires and surveys and deeper ones (such as interviews) allowed for fulsome data collection. This provides for authentic findings through triangulation (through the convergence of information from different sources).

B. Research Methodology

1. Quasi-Experimental Design

To test the research question, part of this research involved a quasi-experimental design. Two separate groups received 13 self-directed e-learning modules and weekly online instruction from a technical instructor along with online tests (for modules) and online exams (for tranches). One of these groups accessed VR experiences as part of the final stages of their technical training[3], while the second group did not. Both groups had the same technical content, tests and exams. Comparisons were made between the pilot group (those accessing immersive technologies) and the comparison group (those who did not use immersive technologies). Participant exam scores were compared between pilot and comparison groups to investigate differences in learning outcomes between the two groups.

[1] A composite material made from pre-impregnated fibers and a partially cured polymer matrix.

[2] Vacuum Assisted Resin Transfer Molding, which is a closed mold, out of autoclave composite manufacturing process.

[3] Using Pico neo 3 pro headsets.

2. Beyond Test Scores

Evidence Synthesis: An evidence synthesis provided knowledge that supports the themes and key areas of inquiry of the research. The evidence synthesis is neither a literature review nor an environmental scan. It is a hybrid, which includes 'evidence' from various sources including but not limited to: subject matter experts (interviews); evaluation reports and studies regarding immersive technologies and their use in technical training; articles in peer-reviewed sources; scans of websites (such as the Canadian Council for Aviation and Aerospace) and grey literature from various sources such as conference presentations.

While the evidence synthesis was undertaken between June and September 2021, conversations with key informants raised areas and issues not explored previously. Therefore, further work was done in January 2022 which explored the evidence regarding the impact of XR in recall/retention and the impact on learners. As a result, findings were added to the evidence synthesis in terms of XR's impact in recall/retention.

Participants: Other data was collected from both pilot and comparison participants, including participant information. This included demographic and job experience information. A pre and post participant survey was also collected, providing information about their learning experience and other aspects affecting learning outcomes. Finally, interviews were undertaken with selected participants.

Key Informants: Interviews with key informants were undertaken throughout the research, including but not limited to those most involved in the development and delivery of the COAST technical training, others involved in aerospace technical training, those using immersive technologies for learning in sectors other than aerospace, employers, and sector leaders.

A summary of the process is provided in the graphic below.

Evidence Synthesis

- A total of 49 sources were included in the evidence synthesis
- A total of 5 telephone interviews were undertaken as part of the evidence synthesis

Participant Test Scores

- A total of 50 participants (25 pilot and 25 comparison) completed the Tranche 1 exam
- A total of 48 participants (24 pilot and 24 comparison) completed the Tranche 2 exam
- A total of 31 participants (10 pilot and 21 comparison) completed the Tranche 3 exam

Participant Voice

- A total of 52 participants (27 pilot and 25 comparision) completed the pre-survey and a total of 7 completed the post-surey
- A total of 5 participants were interviewed by telephone

Key Stakeholders

- A total of 8 telephone interviews were undertaken with representatives from the companies involved in the COAST Composite Technician program
- A total of 13 interviews were undertaken with key industry stakeholders

Reporting

- Quarterly reports of findings were provided in September and December 2021, as well as March 2022
- Final reporting was completed in July 2022

C. Research Limitations

The following limitations need to be considered when interpreting the research findings.

1. Evidence Synthesis Sources

It is possible, and indeed likely, that some sources relevant to the evidence synthesis were not found. Only publicly available sources were accessed for this aspect of the research. Research into XR in learning, and technical learning in particular, is conducted by aerospace and engineering companies and is proprietary to those entities or their funders. In addition, only sources in English and French were included in the evidence synthesis.

2. Reduction of Test Intervention

At the onset of the research process, it was anticipated that the COAST Composite Technician Training program would include VR experiences in the final tranche of the program and focus on the five companies' common experience of the lamination, post-lamination and assembly processes. However, as the project advanced, it became clear that each company had nuances and differences in their lamination processes. Therefore, it became important to create different VR experiences for trainees from different companies in order to more closely emulate what was occurring on the shop floor. Because of time and budget restrictions, this resulted in VR experiences being created exclusively in Module 11 of the training, versus being spread throughout multiple modules of Tranche 3. Findings from the evidence synthesis suggests that this reduction of the VR experience (the test intervention) may not produce a detectible effect because of limited experience or exposure to the intervention. From a research perspective, this is sometimes referred to as 'dosage.' Because the intervention, in this case the VR experiences, were short and not numerous, the intervention 'dosage' may not be sufficient to produce a detectable difference in learning.

3. Assessments

The COAST Composite Technician Training program was a new technical program, piloted for the first time during this project. For this first year of the program testing was based on participation and knowledge.[4] The assessment instruments included tests after each module (except for the first three modules) and exams at the end of each Tranche. These were created by the program's Learning and HR Specialist as well as technical subject matter experts to meet the needs of the participating companies.

Training and learning materials were designed from agreed-upon Technical Learning Objectives based on jobs at the companies, not existing or imported curriculum or traditional set of required skills. These were analyzed by industry experts and reviewed by experienced learning and development consultants, so that all learning content relates directly to what is necessary in these specific target jobs. Exam questions were then derived from the job itself. Test questions were reviewed by an industrial psychologist for construction, order and other issues that could affect answers from trainees. As a final step, a review by subject matter experts took place to ensure all questions were job related, based on only content in the learning material and required in the performance of the job. Once administered, test items were reviewed again by answer option selection to see if any changes were required. The assessment tools allowed for the trainees to complete and receive the course completion certificate with program content and testing having face-validity.

However, due to timing constraints, the program was designed and implemented simultaneously. Therefore, there was not time for the assessments to be tested and/or piloted to ensure validity and reliability and with respect to the key research question - does integrating immersive technologies enhance aerospace technical training and lead to better learning outcomes? As a result, from a research perspective it is not possible to know if the assessment tools measured what they were intended to measure and if these measures are consistent across time and/or items. Indeed, it is possible that the assessments were not granular enough to detect any difference or a measure of change in learning outcomes between the two groups – immersive and non-immersive.

[4] In future iterations of the program, the plan is for performance certification based on industry approved Technical Learning Outcomes, both theory and application, of each skill competency on the job by the trainee.

The participants who received training were existing employees being upskilled. This set the bar high for immersion to show effect. COAST technical programs are also designed so that 65% constitutes a passing grade. Because of this, results from tests and exams are not normally distributed and are skewed right with all scores being between 65% and 100%. This may affect the ability to show significant differences in aggregated scores by group.

4. Group Size

The original research design included 66 individuals across five companies. This would have allowed for pilot and comparison groups to be over 30 individuals each, thus meeting the accepted sample size according to Central Limit Theorem, while allowing for some attrition. Unfortunately, one company's lamination process could not be accommodated via a VR environment. As a result, all these individuals undertook the non-immersive stream of the Composite Technician Training program and were therefore not included in the research. The loss of these 10 participants still allowed for generalizable results, with a sample size of 56.

However, additional constraints became evident as the program progressed. Due to the continuing impact of the COVID-19 pandemic and business pressures, one company had to withdraw from the program just prior to the third tranche exam, after trainees had completed two tranches. This also depleted the sample size. Finally, there was a technical issue with the design of the immersive experiences which resulted in a number of participants in the pilot not accessing the entirety of the VR experience or only accessing some of these. This resulted in a total of 13 individuals who accessed all of the VR experiences in the pilot group and 23 in comparison. This small group size deceases the likelihood of finding statistically significant results and cannot be generalized.

There is potential for the COAST Composite Technician Training Program will be offered in future, creating the opportunity for more data to be collected and added for analysis.

5. Participant Selection

The companies involved in the COAST Composite Technician Training program chose to upskill their participants from their existing workforce. In a number of cases, trainees have already been working as Composite Technicians, some with considerable years of experience on the job. Participants' familiarity with the competencies required for the role may have influenced the results of the research by contributing to a ceiling effect in the pre and post survey of participants' knowledge and confidence in competencies.

D. XR Technologies Primer

From UP360

Extended reality (XR) is an all-encompassing term referring to a collection of immersive technologies including Virtual Reality, Augmented Reality and Mixed Reality. As of today, there is no universally accepted definition of XR technology and what is or is not included in XR. Ask three different people and you will get three slightly different answers. The definitions and categories presented here and in more detail in Chapter 5 are intended to make it easy to understand each form of XR within the context of education and training in the aerospace industry.

THREE MAIN FORMS OF XR

Virtual Reality

Put a headset on, pick up controllers and immerse yourself in a digital world or training simulation of your choosing. With VR, you're completely closed off from the real world around you.

Augmented Reality

One of the scalable, but least immersive forms of XR. Using a smartphone or tablet with a camera, you can see and interact with digital objects in the real world through the window that is your screen.

Mixed Reality

A true blend between the real and digital world. Through a pair of glasses that understand your physcial space, you can see and iteract with digital objects that apear within the real world around you.

1. Virtual Reality

Virtual Reality (VR) is a technology used to fully immerse an individual into computer generated worlds or experiences. The real world temporarily ceases to exist while participants look around, move around and often times even interact with the digital reality that VR enables.

Although there are many different forms of VR, each requires two main components. The Head Mounted Display (HMD) and a computer-generated experience. These experiences can be fully animated with 3D objects and worlds created from scratch or they can be created by stitching together real-world photos and videos captured with a specialized camera.

VR headsets can range in both cost as well as immersion. The higher end equipment, though more expensive, can enable significantly more immersive and realistic experiences. All VR can be broken into two classifications Three Degrees of Freedom (3DOF) and Six Degrees of Freedom (6DOF). 3DOF VR allows users to look up, down and side to side, but doesn't allow any forward or backwards movement. These experiences are typically the end result of content captured with a specialized 360 degree VR camera. 6DOF VR allows for the tracking of translational motion as well as rotational motion, giving the user more freedom and an ability to perform real life tasks.

2. Augmented Reality

Augmented Reality (AR) is a technology used to overlay computer-generated objects or animations in the real world. The technology works by utilizing the camera and display of a smartphone or tablet. The camera captures a real-time recording of the world behind it, while the display superimposes a digital object on top. Traditional AR experiences require some type of physical marker for the digital object to stick to. As the user moves a device around, the object stays fixed to the tracker, creating the sense that the object is really there.

More modern AR experiences can now incorporate things like physics, audio and other forms of haptics to make the experience realistic. It's important to note that, unlike Virtual Reality which is designed to immerse the user into completely new worlds, Augmented Reality is designed to change the real world around them. The biggest limitation of AR is the need to hold a device in your hand and look through a screen to see the experience.

3. Mixed Reality

Mixed Reality (MR) is the newest and most unique technology in the XR family. It can be thought of as a hybrid between VR and AR, although some people prefer to call it another form of AR. Like VR, MR requires the user to wear a specialized set of goggles and like AR, MR glasses still allow the user to see the world around them. With Mixed Reality, the real and digital worlds blend seamlessly together as interfaces are projected through the glasses. Since the device is worn on the user's head, one can simply use hand gestures to interact with the content and navigate digital screens. MR is often referred to as hands-free computing since the device is more powerful than the average laptop which allows a user to perform almost any task a computer could.

2

Evidence Synthesis

An evidence synthesis grounds the themes and key areas of inquiry of the research in what is already known. The evidence synthesis is neither a literature review nor an environmental scan. It is a hybrid, which contains ‘evidence’ from various sources, including but not limited to: subject matter experts (interviews); evaluation reports and studies regarding immersive technologies and their use in technical training; articles in peer-reviewed sources; scans of websites (such as the Canadian Council for Aviation and Aerospace etc.) and grey literature from various sources such as conference presentations.

A. Parameters for Inclusion

The nature of an evidence synthesis involves 'casting a wide net,' and not limiting a study to peer reviewed sources. Industry sources, including reports and publications were also considered, as well as those recommended by the DAIR/OAC project implementation team.

The most recent systematic review of immersive technology in higher education was published this year, and includes sources published since 2017 (Hamilton et al. 2021). Because immersive technologies are evolving quickly, information/evidence dating back approximately five years was most frequently sought for inclusion in the evidence synthesis. However, the emergent design also provided references to earlier work.

Finally, this research focuses on training and skills development in the aerospace industry and within the Canadian context. Other applicable areas of training and learning were also included, particularly in manufacturing. In addition, a focus on the adult learner was essential to ensuring the evidence was relevant to this project.

B. Emergent Themes

Examination of the sources included revealed four emergent themes that provide evidence pertinent to this research, including:

- The immersive technologies landscape in Canada and research landscape of immersive technologies in adult and higher learning experiences
- Reasons for including immersive technologies in adult learning experience
- The impact of immersive technologies on adult learners
- The challenges of incorporating immersive technologies in adult learning experiences

THE LANDSCAPE

A. The Immersive Technologies and Learning Landscape

1. What are Immersive Technologies?

Many recent sources discuss the differences between various immersive technologies, explaining differences between virtual reality (VR), augmented reality (AR) and mixed reality (MR) in terms of origins, technological requirements, individual experience, uses and best practices (Moses et al, p. 2). This particular project involves research immersive training experiences using Oculus Quest 2 head-mounted display (HMD) which is often referred to as Immersive Virtual Reality (I-VR). Therefore, sources and findings regarding I-VR and learning experiences involving HMD are explored in greatest detail.

Irrespective of the mode of delivery, immersive experiences are generally comprised of three principles – immersion, interactivity and imagination – often referred to as the VR Triangle (Concannon et al, p. 3). Radiante et al describes immersion as, "the involvement of a user in a virtual environment during which his or her awareness of time and the real world often becomes disconnected..."; interactivity as, "the degree of accuracy and responsiveness a user's actions represent when using the input hardware..."; and imagination as the deep sense of being present in the immersive 'world' while knowing they are not actually situated in it (p. 4). Levels of fidelity are often described as how much the immersive experience adheres to these three principles, meaning that those providing high degrees of immersion, interactivity and imagination would be considered to have the highest level of fidelity and be closest to a real-life experience.

Although 'level of fidelity' is one way of categorizing immersive experiences, the highest fidelity level for all three principles may not be needed to achieve the goal of the immersive experience: "...not all VR setups attempt to emphasize all three features (immersion, interaction and imagination) in a virtual environment. For example, a surgical simulator, designed for skill training, requiring force, and haptic feedback controls would place interactivity above immersion and imagination." (Concannon et al, p. 4)

2. Immersive Technologies in Learning Environments

Immersive technologies are being incorporated into workplace learning, as well as into adult learning experiences in academic settings, particularly in science and engineering (Hamilton et al, p. 1). Workplace training is being used to onboard new employees and provide workplace or sector specific situational and skills learning. Although a number of sources refer to using immersive technologies in the aerospace sector, much of this pertains to simulator training rather than head-mounted I-VR.

3. What's Driving the Inclusion of Immersive Technologies in Learning?

Several trends are driving the inclusion of immersive technologies in learning, including improvement in technologies themselves, decreased cost for the user, increased availability of equipment and changes to learning environments resulting from the COVID-19 pandemic.

- Technological improvements: lighter and more sensitive equipment (HMDs), untethered access (Moses et al, p. 6)
- Decreased cost: Cost of user equipment is decreasing, although cost of production of VR content remains an obstacle (Farmer & Matthews, p. 45)
- Improvement in connectivity: "While there is ample evidence that immersive technology can be successful in many contexts without 5G, the quality and reach of future VR, AR, and MR solutions will likely benefit from improved network capacity resulting from 5G." (Farmer & Matthews, p. 16)
- The COVID-19 pandemic has normalized remote working and learning: "As organizations implemented new digital approaches to get work done, the benefits of these changes emerged. Even after the pandemic runs its course, it's likely many companies won't want to revert to old methods. Reality has shifted, and with it, the advantages of XR have soared from aspirational to essential." (Fillimore & Storr, p. 2)

B. The Research Landscape

Searches reveal different information sources about immersive technologies in learning and training environments. These include articles in academic peer-reviewed journals, where the conclusions drawn are supported by verifiable evidence:

> *...two main research streams. First, studies that examine the user experience and the effects of unique system features of immersive technology. Second, research that scrutinizes how the use of immersive technologies enhances user performance... (Radiante et al, p. 5)*

However, these sources often explore very specific research topics, and may not be relevant to this research. Furthermore, Hamilton et al point out; "...research focusing on learning outcomes, intervention characteristics, and assessment measures associated with I-VR use has been sparse." (Hamilton et al, p. 1) In addition, a lack of strong research including a comparison group is also a limitation.

In addition to academic sources, there are business and industry sources, such as trade journals and information/reports produced by specific companies and/or sector associations. While these provide applied and 'real world' information, their goal is largely marketing. In many of these sources, the data presented has limitations which tempers their evidential usefulness and ability to draw strong, evidence-informed conclusions.

1. Validation of Current Research Design

The landscape of available evidence regarding I-VR in higher education and skills training suggests the need for more comprehensive studies, not only involving comparison groups but also providing evidence that is triangulated from a number of sources and gathered through various methods:

> *...to fulfill the aim of deriving best practices and of describing useful application cases, better evaluation procedures are needed. It is typical that experimental works place the main focus on usability. However, future educational VR 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. Evaluations of educational VR applications need to be conducted both in terms of technical feasibility (i.e., from a software engineering standpoint) and of the learning outcomes (i.e., from a pedagogical standpoint). We also suggest that future evaluations assess whether developed applications reflect the users' needs, from the perspective of both teachers and students. Thus, future research needs to include workshops, surveys, and focus group discussions in order to extract the necessary learning content and the expected learning outcomes as well as the usability requirements for VR applications from teachers and students. (Radiante et al, p. 22*

Because the current research includes a comparison, several data sources and is multi-method, this research has the potential to inform the possible inclusion of I-VR in Canadian aerospace technical training.

FINDINGS: Why Incorporate XR?

Information from business and industry sources help to answer the 'why' question pertaining to the inclusion of immersive experiences in higher learning and training. A recent publication from Farmer and Matthews succinctly summarizes this by stating I-VR is most efficiently used in areas that would be challenging to undertake in real world environments: "...immersive technology is most valuable when it improves or replaces costly, time consuming, and dangerous processes, and/or where it enables new processes that were once not feasible" (Farmer & Matthews, p. 18).

Importantly, including I-VR in learning and training will be most successful if it is not driven by the technology itself, rather how it provides value added to the experience. Within aerospace technical training, this means I-VR will have the most impact in situations where it can demonstrate a benefit to learning or provide opportunities not otherwise available through existing in-person or remote learning:

> *The incentives for immersive VR being incorporated into post-secondary education and skill training may include one or more of the following: the maintenance of ethical principles, overcoming problems concerning time and space, increasing the physical accessibility of environments that are not normally accessible and/or overcoming what would normally be a dangerous situation (Concannon et al, p. 7).*

More specifically, Makransky and Peterson stress the importance of ensuring immersive learning experiences take advantage of the potential of the medium to affect learners' presence and agency:

> *...interaction and immersion are limited with lessons presented on a video or PowerPoint, but are greater with IVR or other existing/future immersive technologies. So, students' presence and agency, which are psychological constructs that arise from immersion and interaction, will generally be higher in immersive media. This means that instructional methods that enrich learning through higher presence or agency will specifically increase learning through immersive technology (Makransky and Peterson, p. 4)*

A. To Solve a Problem

While it may seem self-evident that solving a learning 'problem' would be the place to start when integrating I-VR into learning/training, evidence indicates is not always a driver. As mentioned to Tim Jung, Founder of the AR and VR Hub at Manchester University, "Instead of looking at technology first, I think we should go back to what the issues and problems are with training…expertise involvement is so important. We should ask if there is any way technology can help as a tool" (Bevilacqua, p. 5). This draws attention to the capacity of I-VR to solve learning 'problems' such as safety, the need for repeated practice to gain mastery, to reduce materials waste or free up critical equipment time.

B. Have a Demonstrable Benefit

Similarly, the VRARA Association advocates the use of I-VR in learning opportunities where there are demonstrable benefits to the learner: "As the field of instructional technology pivots quickly to VR, online learning developers must choose the correct strategy for creating the experience. Otherwise, learners will have a "cool" experience in the VR environment but not receive any tangible learning results" (Ochoa, p. 18).

Because the impact of I-VR in learning environments is still emergent, Ochoa cautions against the inclusion of immersive technologies simply for their own sake, as possible misplaced use of these technologies will hamper widespread adoption: "The problem is that most online learning developers have never experienced VR and will have a hard time applying traditional instructional design methods to the VR space. It is important to avoid mistakes early in the process so designers do not end up creating bad VR classrooms. VR design strategies must go beyond traditional instruction to truly leverage the advantages of VR for learning" (Ochoa, p. 18.).

C. To Increases Access

Providing rich learning experiences through integrating I-VR has the potential to solve issues of access. Within aerospace technical training, I-VR could provide learning opportunities for individuals in more remote centres and avoid travel. Cost and time savings could also result from individuals' ability to access training remotely, while still having access to experiences that simulate real-world production and maintenance environments (Concannon et al, p. 14).

D. To Increase Safety

By providing a learning experience that mirrors real-world situations, locations and actions, I-VR has the potential to provide safe learning opportunities that conform to ethical principles: "It is a safe, ethical and repeatable system that produces objective measures of performance while providing real-time feedback to users" (Alaker et al., 2016). Concannon et al takes this notion further by outlining the learning/training situations in which I-VR might impact safety:

> *A virtual environment that focused on safety may have included some or all of the following: (a) The practice of awareness skills necessary to reduce the probability of accidents occurring, (b) The practice of technical or non-technical skills necessary to handle an abnormal operating condition, (c) The ability to interact with virtual objects that would be deemed too dangerous in the real world. Some virtual environments were mentioned to have been programmed to allow for damage to occur within the virtual world, allowing users to safely learn from mistakes that would normally cause real-world machinery to collapse or cause personal injury (Concannon et al, p. 15).*

E. To Meet Training Demand

Might the demand for training in Canadian aerospace outstrip the sector's capacity? Rapid technical changes in production and maintenance suggests the possible need for continuous up-skilling of staff. According to the World Economic Forum, "By 2022, no less than 54 percent of all employees will require significant re- and upskilling" (Greene, p. 9). Could the inclusion of immersive technologies in sector learning reduce the need for onsite expert trainers for staff up-skilling?

Sources provide information regarding the use of I-VR in the onboarding of new staff, and the opportunity for repetition in a low-risk environment could impact onboarding in the aerospace sector (Fillmore & Storr, p. 4). However, the case studies readily available about I-VR and the training of new staff are largely in the area of soft skills and where affect and social and emotional experience impacts learning. In addition, these sources do not provide verifiable evidence into the statements made about the impact of I-VR on learning.

FINDINGS: Impact on Learners

A. Impacting Learning is Important

Business, industry and academic sources all stress that enhancing learning is where the potential impact is greatest with XR. Therefore, the measure of success for the inclusion of I-VR in learning and training is the impact on the learner experience, which builds individual capacity: "For I-VR to gain wide-spread acceptance as a reliable pedagogical method, it must be shown to confer a tangible benefit in terms of learning outcomes over less immersive or traditional teaching methods" (Hamilton et al, p. 16). Impacting individual learning could lead to more efficient job performance, thus increasing the capacity of the sector workforce generally.

Researchers in the field reiterate that the impact on learning should be the focus of what drives the inclusion of XR in learning generally. This would apply equally to technical training in the workplace or in virtual or in-person classrooms: "There is a big push for enhanced technology in classrooms. I think we can be in awe of these fancy, shiny devices and it might feel like they are helping, but we need to know if they actually are" (Cornell University, p. 1). Clearly, further robust research is needed to dig more deeply into the impact of these new technologies on learning.

Madden et al's 2020 publication on the predictors of learning points out: "Measures of learning from VR are generally conflicting. Studies have found that participants in VR learn more than, as much as, or less than participants in hands-on or desktop conditions." These researchers clarify that it is not simply the inclusion of VR that opens the possibility to impacting learning outcomes, rather it is how it is used and how well the experiences are constructed that matter: "The existing research exemplifies the idea that it is not the technology, but how it is used, that promotes learning." This is not surprising considering what has been well established in the pedagogical literature for years.

B. Impacting Learning: What Do We Know?

There is a body of evidence that suggests VR impacts learning by enhancing recall and retention, focus and enjoyment. Regarding retention, VR's possibility of immediate feedback supported learning: "When learning was improved in VR over a hands-on activity, the gains were attributed to immediate feedback available through the simulation and visualization of the abstract phenomenon that was otherwise imperceptible in the hands-on activity" (Madden et al, p. 4).

Enhanced recall and retention is often associated with being able to 'see' and being visually present in the learning experience. While this is explored in the evidence on visual and spatial learning, experiential learning theory reminds us of the importance of the bodily and movement experience as enhancing learning:

> *Being able to visualize and see in an immersive space was the key to this [see Krokos, Plaisant and Varshney] improvement in recall results. That's because, with VR, the experience is a true feel in stepping into a space and allows them to create their own lived experiences digitally. It is the act of leveraging a person's natural ability to sense body position, movement, and acceleration that can enhance learning (Chan, N.P.)*

Information about XR and learning also hinges on the notion that it provides a better focus by eliminating distraction. This is most commonly discussed in information about HMD VR: "It is this zoning in effect that helped participants experience the 'superior sense of spatial awareness which claimed was important to their success'" (Chan, N. P.) The 'locked in' nature of HMD VR provides for less visual and audio distraction and supports the notion of increased focus.

Finally, Cho's study on VR learning of an additional language points to the possibility that immersive technologies impact learning by increasing enjoyment: "Essentially, when navigating unfamiliar topics or environments, Cho notes that 'enjoyment reduces stress and fear', giving participants a new sense of motivation and something to look forward to" (Chan, N.P.). This suggests that if XR can increase the enjoyment of the experience, learning is enhanced. However, Madden et al disagreed; "…the researchers also argued that the enjoyment associated with VR actually distracted the learners from learning" (p. 4).

C. I-VR and Visual/Spatial Learning

Evidence suggests immersive technologies are impactful with learning spatial and visual knowledge tasks: "HMD VR is useful for skill training including the training of cognitive skills related to spatial and visual knowledge, psychomotor skills related to head-movement, visual scanning, observational skills…" (Concannon et al, p. 14). Systematic reviews by Hamilton et al, and earlier by Jensen and Konradsen, suggest I-VR's capacity to engage multiple senses contributes to visual/special learning:

> *Researchers have suggested that the increased levels of immersive content that stimulate multisensory engagement can ultimately lead to more effective learning outcomes. When this is implemented in cognitive learning activities that require a high degree of spatial understanding and visualization, I-VR can allow the user to gain insights that are difficult to reproduce in reality (Hamilton et al, p. 24)*

It should be noted that these two sources reviewed studies pertaining to science learning, and not specifically to technical training. However, this work does suggest possible application to more applied contexts.

These authors further caution that systematic review of studies involving I-VR did not impact all areas of learning: "Outside of these situations [visual/spatial knowledge] the HMDs had no advantage when compared to less immersive technologies or traditional instruction and in some cases even proved counterproductive because of widespread cybersickness, technological challenges, or because the immersive experience distracted from the learning task" (Jensen and Konradsen, p. 1)

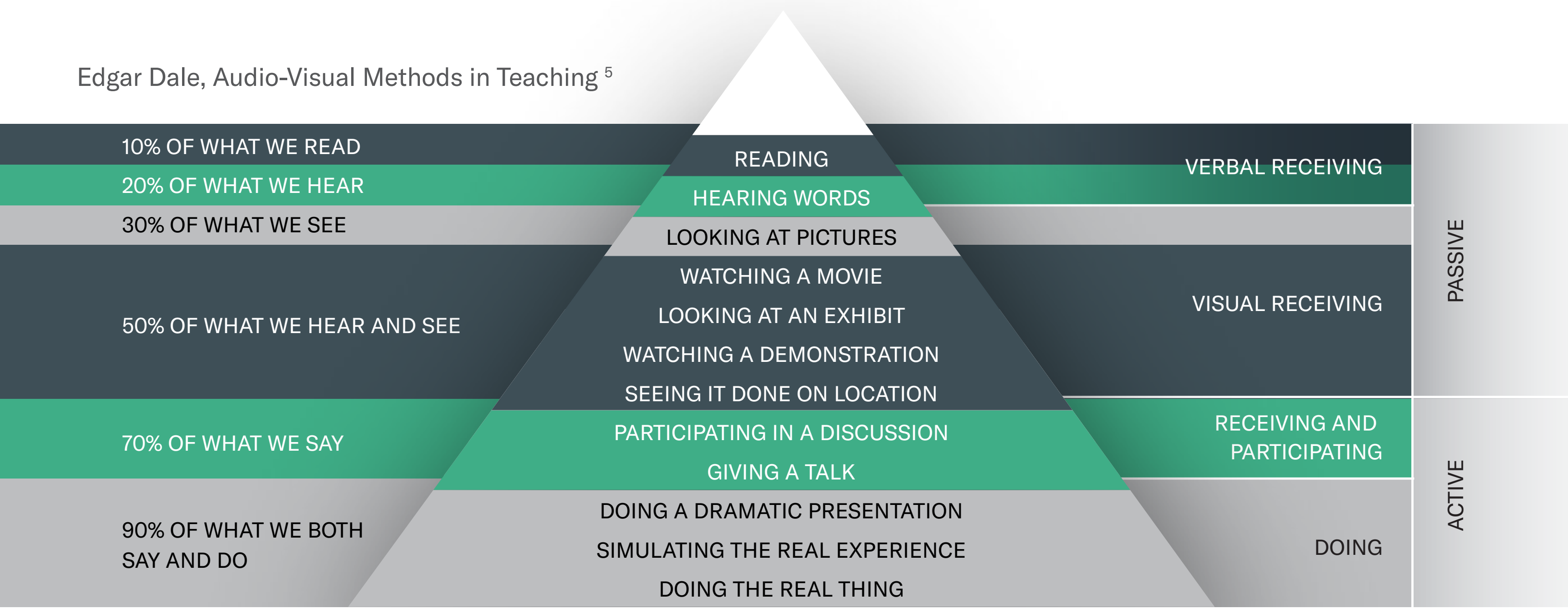
D. I-VR as Experiential Learning

Experiential learning is a well-known pedagogical theory, and is often summarized as 'learning by doing.' David Kolb theory of experiential learning is built upon how action and reflection reflect organic and meaningful experiences as the learner moves through the experiential cycle: "The core assumption is that students optimize learning and practical skill acquisition through experiential learning and hands-on experience…" (Concannon et al, p. 5). This theoretical framework also stresses the importance of real-world relevance and opportunities for repetition and mistakes. Contemporary neuroscience enters the experiential learning picture by supporting that practicing skills and repetition strengthens neural connections in the brain:

> *Much of the marketing for these training-focused VR platforms draws on a commonly accepted principle that experiential training is more effective, and the information retained for a much longer period than more traditional methods, such as listening to a lesson and taking notes, reading a textbook, participating in a group discussion or watching a video presentation (Ricco).*

Experiential learning builds on Edgar Dale's ground-breaking work, *Audio-Visual Methods in Teaching*, by emphasizing the impact of simulating a real experience and participating as necessary to reach an effective assimilation and retention of knowledge.

Edgar Dale, Audio-Visual Methods in Teaching [5]



[5] Edgar Dale, *Audio-Visual Methods in Teaching* (3rd Edition), Holt, Rinehart, and Winston (1969); https://www.researchgate.net/figure/Edgar-Dale-Audio-Visual-Methods-in-Teaching-3rd-Edition-Holt-Rinehart-and-Winston_fig1_283011989

Business and industry sources provide examples of how immersive technologies support experiential learning: "…XR's experiential learning can help employees acquire skills to meet the necessary performance levels faster. By using AR instead of documentation, one manufacturer reported astounding results: a 90-percent increase in the number of trainees with little or no experience who could perform a complex, 50-step operation correctly the first time" (Porter & Heppelmann). Much of these examples focus on the individual's knowledge and competency in a specific task (Concannon et al, p. 15). However, the reader is cautioned when considering all I-VR to have a positive effect of learning. Learning does not become more experiential simply by adding XR. Attention needs to be paid to ensuring the XR learning activities are as 'hands on' and participatory as possible.

As mentioned above, immersive technologies allow for the possibility of visual and movement-related simulations and how this impacts experiential learning:

Research has found, however, that performance is improved when participants can more fully interact with the simulation: for example, walking around the simulation compared with remaining stationary while looking around the simulation. Furthermore, one study found that students' reported sense of presence in a simulation was correlated with their learning from the simulation. This study also found that preferential learning from VR was confined to sub-topics involving "dynamic three-dimensional processes, but not processes that can be represented statically in two dimensions". This suggests that VR simulations are more effective when they take advantage of their specific affordances (Madden et al, p. 4)

Ensure design of learning experiences are as 'real life' or experiential as possible should also consider how the learner moves, as well as what they can see or touch.

E. I-VR and Procedural Learning

Procedural knowledge involves 'how to do something' as demonstrated through behaviour rather than conscious memory or recollection, such as driving a car. Hamilton et al found encouraging results for immersive technologies in procedural stills learning: "Studies that utilised I-VR for the teaching of procedural skills and knowledge produced encouraging results, with three of the four studies finding a significantly positive increase in learning" (Hamilton et al, p. 24). Similarly, Radianti et al found: "…IVR provides optimal conditions for rehearing procedures through the appropriate provision of appropriate sensors such as hand control devices…" (Makransky & Peterson, p. 12).

This finding is particularly impactful for the present research, as Hamilton et al and Jensen and Konradsen were the only two that reviewed studies with a comparison group. Hamilton and his colleagues take this one step further by stating, "…most procedural tasks did show a benefit to utilising I-VR, and furthermore, there was evidence that virtual skill acquisition could be transferred successfully to real world problems and scenarios" (Hamilton et al, p. 24).

The importance of repetition in skill-based procedural learning is another area where immersive technology appears to impact learning. Again, this may seem intuitive, but is also evidence-based: "VR enables repetition learning anywhere, anytime. On-demand repetition training helps improve long term retention" (Belch, p. 18).

F. I-VR and Learner Engagement

A number of sources indicate immersive technologies will impact learning by providing and engaging experience. Business and industry sources make this claim, but often do not provide supporting evidence. However, a large body of literature on learner engagement is available from peer reviewed sources, and Makransky and Peterson examine this notion regarding IVR learning. This source points out that IVR's immersive and interactive potential enhance the learner's presence and agency: "…instructional methods that enrich learning through higher presence or agency will specifically increase learning through immersive technologies" (Makransky and Peterson, p. 4). Concannon et al agrees, stating, "…engagement allowed a user to feel involved in the learning process, usually by being offered challenges or interactive elements within the educational virtual environment" (Concannon et al, p. 15). It is important to note that these authors, as well as others, differentiate between engagement and attention/focus or enjoyment/fun (Concannon et al, p. 4).

G. I-VR and Knowledge Transfer

Although immersive learning experiences are an emergent practice, some sources suggest knowledge transfer from simulated to real world applications is facilitated by close replication of real-world environments: “By providing virtual simulations of real-life performance situations, transfer of learning to actual real-life situations can be enhanced through IVR. Such transfer can both be procedural…or conceptual…” (Makransky and Peterson, p. 12)

H. I-VR and the Adult Learner

Much is known about how adults learn differently from children. Adults learn best when their opportunities are self-directed, goal-oriented, practical, active, respectful, acknowledge their experience, matches their learning style and allow for feedback. Parallels with experiential learning are evident, and the role I-VR can play in experiential learning applies to meeting the needs of adult learners. Keeping in mind more mature learners may have been removed from structured learning environments for some time, I-VR may provide opportunities for situational, experiential and practical learning (Schwartz, p.2).

XR may affect learners differently depending on their age: “Digital natives are characterized as having access to networked digital technologies and the skills to use them… To meet the unique learning needs of “Digital Natives”, digital tools are able today to respond immediately to the natural, exploratory and interactive learning style of the students” (Lappas & Kourousis, p. 234). As millennials become an increasingly larger percentage of the workforce, it is important to keep the learning needs and experiences of these adults in mind when seeking to provide impactful learning experiences:

Millennials are playing a major role in the revamped learning strategies taking place in many organizations right now…. millennials’ belief that VR products will increase productivity …Millennials are already using VR for gaming and are twice as likely than other generations to purchase a VR headset (Greene, p. 9)

Understanding the individual’s experience as a principle of adult learning emphasizes consideration of the lived realities of younger adults, whose life experience is characterized by instant communication and real-time response. Cortiz and Silva suggest, “…emerging technologies, especially Virtual Reality, could be used to improve learning process for a generation that could not pay attention to a lecture for long period and has serious problems to attend online learning tasks as we have discussed before”(p. 4).

Finally, there is some evidence that individuals who have more video gamming experience are better adapted to XR learning. This study points out that gaming experience is correlated closely to gender, with those identifying as male having more experience (Madden at al, p. 4). This suggests that the impact of XR on learning might be greater for younger males than older females. Considerations of these factors in decisions regarding the inclusion of XR in training are warranted.

FINDINGS: Challenges to Incorporating XR

There are challenges to the use of immersive technologies in learning environments, which might influence applicability to aerospace technical training. Farmer and Matthews recent exploration of the Canadian immersive technologies ecosystem provides a succinct descriptions of challenges currently facing I-VR:

Increased adoption of immersive tech in the coming years is likely dependent on headsets and other hardware devices becoming cheaper and more accessible, and use cases and their benefits becoming more widely understood in Canada. With greater adoption, immersive technology has the potential for notable impact across traditional non-tech sectors, providing efficiencies and unique solutions to business problems. Examples include “on-site” planning via VR for remote locations in the natural resource sector and automated assistance in a factory setting through an AR overlay to assist with repetitive tasks. In a more remote and connected future, immersive tech may achieve a broad product/market fit for both consumer and commercial audiences. Defining and building clear use cases, securing necessary funding, and securing and supporting a skilled talent base will be key to unlocking new consumer demand for this budding Canadian industry (Farmer & Matthews, p. 45).

A. Lack of Research Validation

As previously mentioned, some business and industry sources lack strong evidence of the impact I-VR has on learning. Some research seeks to explore the effect of I-VR on learning outcomes, however,

Perhaps VR's biggest obstacle to being accepted into post-secondary education systems is its psychometric validation, where stakeholders must carefully judge the degree to which virtual environments offer training in skills that can be obtained in other less expensive or complex modalities, which are free from simulator sickness (Parsons, 2015).

Plenty of information is available about the potential I-VR could provide in many learning and training situations, although many have not been strongly tested. Until this happens, the value added of using immersive technologies in training remains largely unexplored and unproven:

The companies leading the virtual reality revolution have solved major engineering challenges – how do you build a small headset that does a good job of presenting images of a virtual world...but they have not though as much about how the brain processes those images. How do people perceive a virtual world (University of Wisconsin-Madison, N.P.)

B. User Experience

Continuous improvement to I-VR hardware has made headsets smaller, lighter and more responsive, although "Respondents found user experience, such as bulky hardware or technical glitches, to be the biggest obstacle for mass adoption of AR (26%) and VR (27%)—but that's down from last year, when user experience was at 39% for AR and 41% for VR" (PerkinsCoie, p. 4). Interestingly, Jensen and Konradsen' s systematic review of immersive technologies in higher education suggested the impetus for I-VR hardware and software development remains largely in the service of entertainment and gaming, rather than in explorations for widespread use in educational settings. However, the reader is cautioned this review included sources dating from before 2017, which introduces the possibility that the evolution of I-VR may have made it better adapted to adult learning.

A number of sources also acknowledge cybersickness as inhibiting the use of I-VR's adaptation to learning environments. Golding et al refer to this phenomenon as visually induced motion sickness and present findings about how this phenomenon relates to traditional motion sickness, and how it can be predicted. Cybersickness as a possible inhibitor to more widespread adoption of I-VR in learning environments remains a consideration.

Emotional factors may also warrant consideration regarding the incorporation of I-VR in learning: "Another psychological factor of importance is that some users feel unsafe if their view is "locked" in an immersive virtual world... There is interplay between emotions and learning, but how feelings such as insecurity and emotions in general influence learning is a matter of ongoing research" (Lappas & Kourousis, p. 235)

C. Cognitive Load

Cognitive load is a construct believed to happen in situations when an individual's working memory becomes 'overloaded' by the amount of information needing to be processed. Cognitive load could be a factor within I-VR's multisensory experiences, and should be a consideration in designing learning immersive learning. Ensuring the inclusion of content only relevant to the learning, as well as those support learner focus and attention, may help mitigate against cognitive load and support learning (Makransky and Peterson, p. 16).

XR further challenges cognitive load by requiring more processing of the physical manipulations inherent within the experiences:

The researchers also found that participants in the VR condition had significantly higher cognitive load as measured through an electroencephalogram (EEG). They suggested that the physical manipulation of the equipment in VR was more complicated than the desktop condition, which may have increased students' extraneous cognitive load, impacting learning. They recommended experiments that used more natural control systems to manipulate the environment (Madden et al, p. 4)

D. Cost

While the cost of I-VR hardware is declining, cost of quality content production, particularly in the area of learning, remains high:

> *...scalability is critical for adoption even when there is a strong return on investment. Equipment and maintenance costs and user experience (e.g. ease of use, comfortability, to what degree the technology is compact and mobile, etc.) are important considerations for industry when evaluating whether the investment in immersive technology is worthwhile...When an application can be used comfortably, at scale, and at a low cost, immersive technology can be a very effective tool (Farmer & Matthews, p. 22).*

Again, results from the 2019 PerkinsCoie survey of AR/VR indicate "content offerings were a concern for mass adoption…." (p. 4)

E. Experience, Technical Literacy and Attitudes

The impact of I-VR on adult learners of different ages has been previously discussed, although age may not be the only factor influencing possible learning differences. A number of years ago, RAND "...define[d] technological literacy as "the ability to use computer-based devices, software, and networks," where "use" refers not only to operating the relevant devices but also to "advanced abilities to learn, analyze, and explore" (Ochoa, p. 14). In addition to age, previous learning and life experience may affect technical literacy, as those living on lower incomes have fewer and older technical devices, thus precipitating less opportunities for achieving high technical proficiency.

Finally, attitudinal factors could influence immersive learning experiences: "Apathy or distrust of new technologies are common reactions. There may also be confusion about how the technology will be used, how it works or what the experience will be like" (PWC, 2019, p. 14).

CONCLUSION: What Does the Evidence Tell Us?

Evidence suggests that immersive technologies are most impactful in solving learning problems or where there is value-added for the learner, rather than when use is driven by the technology itself. Careful attention needs to be paid to where immersive technologies will have the most impact on the learner, increasing their capacity and ultimately their performance on the job.

A. Implications for the Learner

- Do not expect that all participants will know how to use XR equipment. **XR users need to be oriented as to how to use the equipment safely.** Have an orientation session with simple graphics about how to adjust their headset.
- First time users may experience unease or feel self-conscious. Before their first experience, **send information about what to expect and encourage learners to try using the equipment in advance of a training setting.** These 'orientation experiences' are meant for users to try on their own to familiarize themselves with the technology and become comfortable in the virtual environment
- Some learners may not adapt well to VR because of disorientation, balance and motion issues (cybersickness). Others may feel psychologically unsafe by being 'locked' in an immersive environment. Implementors should consider screening for possible inhibitors to a positive learning experience such as cybersickness, low technical literacy and attitudes.
- With the **changing demographics of the workforce, attention to the role VR can play in the learning of younger generations** should be a consideration for aerospace technical training.
- When seeking opportunities for the inclusion of XR in technical training, consideration of participants previous experience with similar technologies such as gaming may be a consideration for better learning.
- Evidence is mixed regarding the role of enjoyment of XR experiences and their effect on learning, **with some suggesting that enjoyment results in a decrease in stress and fear, which positively affect learning, while other believe it distracts.**

B. Implications for Design of the Learning Experience

- **Make XR content as compelling and 'real world' as possible.** Evidence indicates that more immersive and interactive experiences enhance learning. **Emphasis should be placed on designing high quality and fidelity immersive experiences.** Learning tasks that are difficult to replicate with slide shows or 2D video should also be considered when seeking impactful I-VR learning possibilities. This is important in terms of learner engagement (presence and agency), enhancing experiential learning, and possibly supporting knowledge transfer.
- The evidence suggests making the XR experiences 'as real as possible' would involve **considerations of immediate feedback, being visually and spatially realistic, leveraging movement possibilities and incorporating touch, feel and resistance. Leveraging movement possibilities include the manipulation of objects in the environment (fine motor) and physically moving and engaging in the XR space (gross motor). However, this should also be balanced with consideration of the cognitive load participants experience,** as excessive cognitive load may hamper learning by inhibiting transference to long-term memory and therefore has implications for recall/retention.
- Embed within learning of cognitive outcomes that involve **a high degree of spatial understanding and visualization.**
- Experiential learning and engagement suggest a value to interactivity in learning. **Skills mastery through experiential learning fosters the learner's agency,** a factor in engagement.
- Having opportunities for users to become familiar in the XR space is suggested above, not only for familiarity, but also in trying to reduce cognitive load during learning activities.
- **Provide opportunities to make mistakes and repeated practice and activities**, particularly when it comes to procedural learning and skill development.
- Because using VR can be a solitary experience, make sure **there are times to debrief and discuss the experience**.
- A number of sources recommend that XR be incorporated into a blended learning environment. Hamilton et al's systematic review of immersive technologies in higher education involved **experiences lasting six to thirty minutes**.

C. Implications for Research

- Research into immersive technologies in skills training should include a comparison group, as studies involving comparison are scare.
- Research should go beyond comparison of learning as measured by test results to include confidence/self-efficacy and possible measures of engagement
- Triangulation with qualitative data from a variety of sources, the learners, the facilitators, the implementation team and employers will support robust findings regarding integrating immersive technologies in skills training.

Evidence Synthesis - Maximize Learning with XR

Findings from the Evidence Synthesis stress paying attention to these factors in order to maximize learning

Orient Learners	Focus on Spatial & Visual Tasks/ Competencies	Ensure a Depth of Experience	Mimic Reality	Repeated Practice, Trial & Error	Sharing and Debriefing
Show learners how to use the technology Give them a chance to try it before the learning experiences	XR will likely have the greatest impact on learning requiring a high degree of spatial understanding and visualization	Sustained XR experiences are more likely to impact learning Optimally, XR experiences should be between 6 and 30 minutes	Make it as close to the real experience as possible Ensure high quality/ fidelity experiences	Provide opportunities for repeated practice Let trainees make mistakes and learn from these	Trainees learn from one another Opportunities to discuss and debrief deepens learning

3

Participant Findings

This chapter presents the participant findings from a variety of sources including learning assessments, a pre and post survey of participants and interviews with selected participants.

A. Findings: Trainee Assessments

The COAST Composite Technician Training program is divided into three Tranches, each with modules providing learning experiences in diverse competencies.

1. Tranche 1 Exam

A total of 50 participants completed a Tranche 1 exam:

- 25 participants in the pilot group
- 25 participants in the comparison group

Tranche 1 included six modules, with the first three being introductions to e-learning, composites and 'a day in the life' of a composite technician. The remaining modules included:

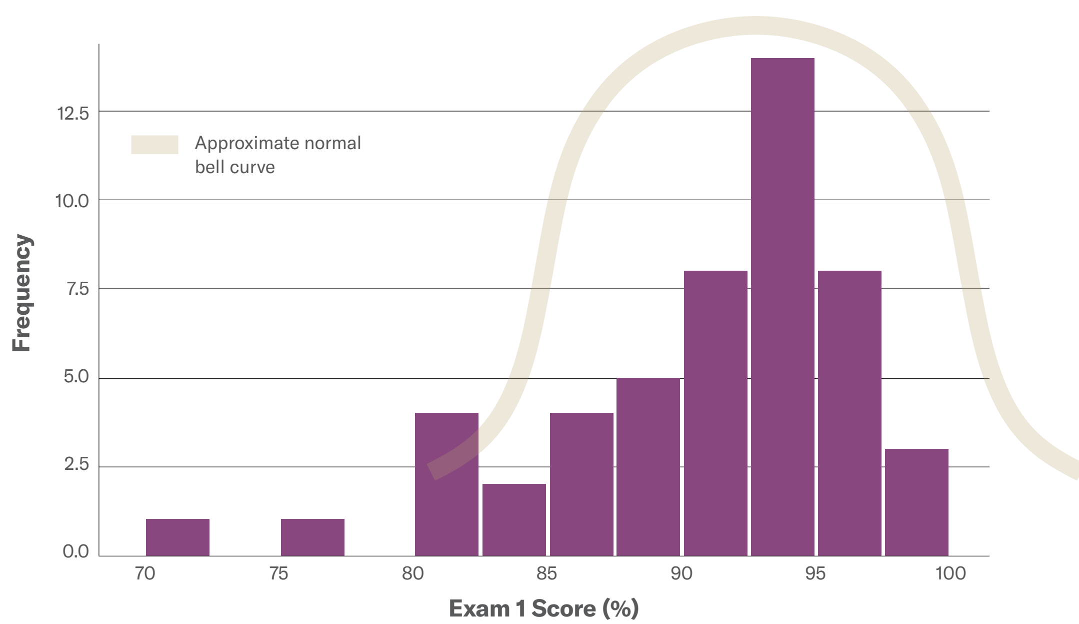
- Module 4: Introduction to Composite Workplace- shop floor safety, 5S/ Workplace Organization; FOD; overview of the three components – lamination, post-lamination and assembly
- Module 5: Math
- Module 6: Work Documents - work direction; quality assurance requirements; material traceability

An exam covering learning outcomes from Modules 4 through 6 was administered to all trainees.

All Participant Descriptive Statistics

- Mean Score (average): 90.6%
- Median Score (middle of the range): 92%
- Mode Score (most frequent): 93%
- Range of Scores: 71% to 98%

Almost two-thirds (66%) of all participants scored between 85% and 98% on the Tranche 1 exam.



Tranche 1 exam scores are fairly normally distributed, meaning the scores fall mostly along a normal bell curve. However, Tranche 1 exam scores are skewed right, as most participants scored high on this exam (85% to 98%).

2. Tranche 2 Exam

A total of 48 participants completed a Tranche 2 exam:

- 24 participants in the pilot group
- 24 participants in the comparison group

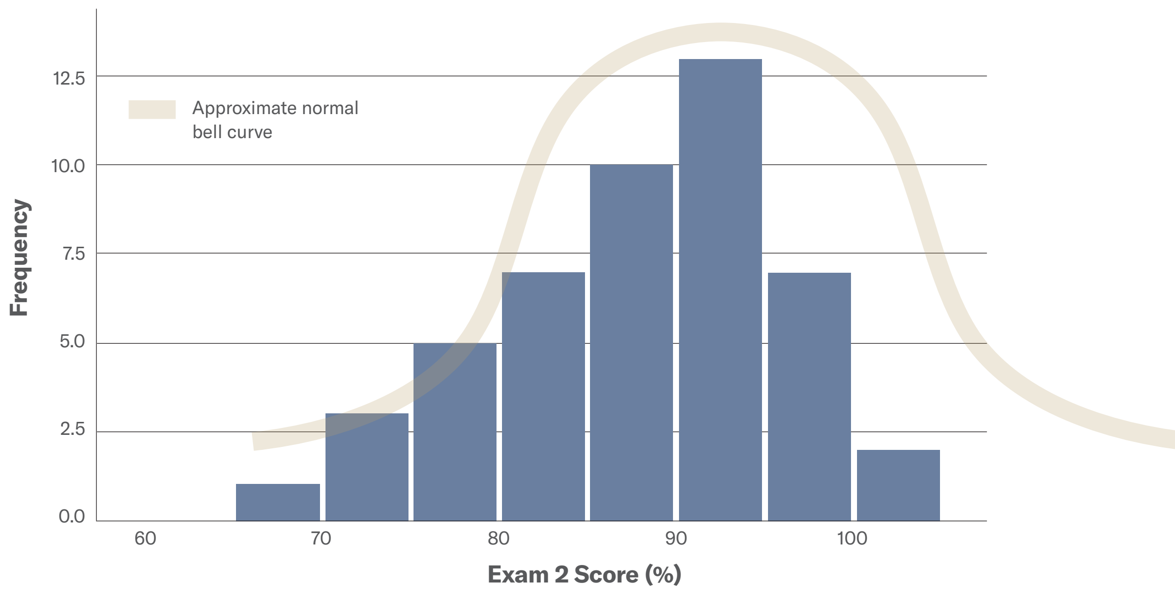
Tranche 2 included the following modules:

- Module 7: Measurement Tools
- Module 8: Hand and Power Tools
- Module 9: Jigs and Fixtures
- Module 10: Materials – composite & metallic materials

All Participant Descriptive Statistics

- Mean Score (average): 87.6%
- Median Score (middle of the range): 88.6%
- Mode Score (most frequent): 94%
- Range of Scores: 66% to 100%

Three-quarters (75%) of all participants scored between 83% and 97% on the Tranche 2 exam.



Similar to the Tranche 1 exam scores, those for Tranche 2 are fairly normally distributed along a normal bell curve. These scores are skewed right, as most participants scored high on this exam (83% to 97%).

Mean (Average) Score: Pilot Group: 89.6%

Mean (Average) Score: Comparison Group: 85.7%

Mean (Average) Difference Between Groups: 3.9%

The difference in mean scores between pilot and comparison groups was not statistically significant (p=.12), meaning the difference in Tranche 2 exam scores between groups is not likely due to any program effect. This is an expected result, as both groups received the same learning experiences. No Virtual Reality experiences were included in Tranche 2.

3. Tranche 3 Exam

A total of 31 participants completed a Tranche 3 exam:

- 10 participants in the pilot group
- 21 participants in the comparison group

Tranche 3 included the following modules:

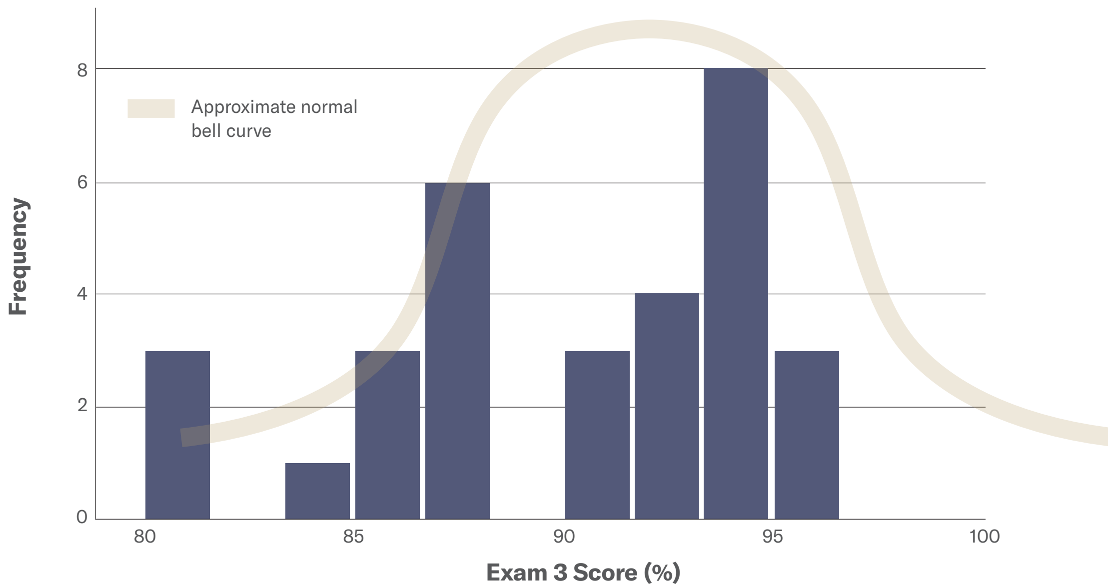
- Module 11: Lamination
- Module 12: Post-lamination
- Module 13: Assembly

Two Virtual Reality experiences were included in Module 11, one involving the pre-preg[6] process and a second involving

Vacuum Assisted Resin Transfer Molding (VaRTM).

- Mean Score (average): 90.1%
- Median Score (middle of the range): 90.2%
- Mode Score (most frequent): 94.1%
- Range of Scores: 80.4% to 96.1%

Almost half (49.4%) of all participants scored between 90% and 96% on the Tranche 3 exam.



Tranche 3 exam scores are not normally distributed and do not distribute along a normal bell curve. This creates challenges in interpreting these findings, as a major assumption (normal distribution) has been violated.

Mean (Average) Score: Pilot Group: 92.5%

Mean (Average) Score: Comparison Group: 89%

Mean (Average) Difference Between Groups: 3.5%

Interestingly, the difference in mean scores between pilot and comparison groups was statistically significant ($p = .047$). However, caution is advised when interpreting this result. As witnessed in the histogram of scores, the distribution is not normal, which can introduce difficulty when interpreting significant results. While analysis reveals a statistically significant difference between pilot and control, the violation of the assumption or normal distribution introduces doubt as to whether this finding is due to the intervention (VR experiences) or some other unknown factor.

[6] Prepregs are composite materials in which a reinforcement fiber is pre-impregnated with a thermoplastic or thermoset resin matrix in a certain ratio.

Comparative Analysis: Pilot and Comparison Groups

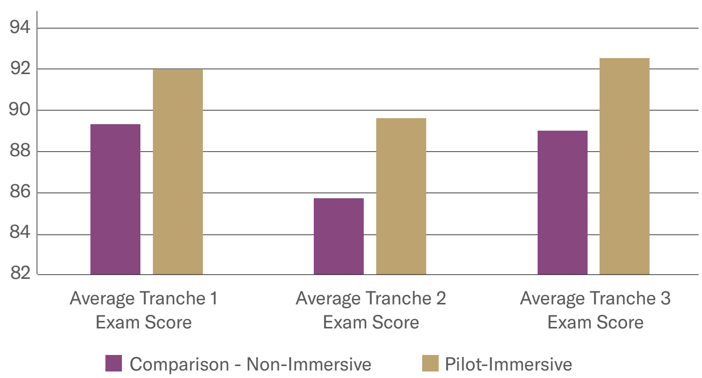
4. Tranche Exams Compared

The table below compares key findings for each Tranche exam scores.

Exam	Mean (Average) Difference Between Groups	Significance (p-value)*
Tranche 1	2.7%	.12
Tranche 2	3.9%	.12
Tranche 3	3.5%	.047

*Statistically significant change indicates the likelihood that this change is due to random chance. A low p-value or probability value of .05 or less is considered statistically significant, meaning that this change is likely due to a program effect.

Average Exam Scores by Pilot and Comparison Groups



Mean Differences and Statistical Significance

This describes the difference between the average scores of the pilot (immersive) and comparison (non-immersive) groups. This ranges from a difference of 2.7% to 3.9%. The largest mean difference between groups was with Tranche 2 exam scores and the result was not statistically significant with a sample size of 48 participants (24 pilot and 24 comparison). Interestingly, the mean difference between groups for the Tranche 3 exam (3.5%) is statistically significant, despite this being less than the mean difference for Tranche 2. What may be concluded from these findings?

- As previously stated, a major assumption for Tranche 3 exam scores has been violated, as it is not normally distributed. While calculations reveal a statistically significant difference between pilot and control, the violation of the assumption or normal distribution introduces doubt as to whether this finding is due to the intervention (VR experiences) or some other unknown factor.
- The sample size for those in the pilot group Tranche 3 exam scores is small, meaning they cannot be generalized.
- The group sizes for Tranche 3 exam scores are different, as there are twice the number of individuals in the comparison group as in the pilot group.

Therefore, the reader is cautioned regarding the interpretation of a statistically significant difference between the pilot and comparison groups for Tranche 3 exam scores. These findings indicate that the inclusion of VR experiences in Module 11 cannot likely account for the difference between groups' Tranche 3 exam scores.

Explaining a Non-Significant Result

As discussed in the limitations section of this report there may be a number of factors that could have led to a result where no significant difference in Tranche 3 exam scores. The small sample size has already been discussed. The validity of all exams was not established through pilot testing. In addition, the VR experiences were short and not numerous, thus introducing the possibility that the intervention 'dosage' may not be sufficient to produce a detectable difference in learning between pilot and comparison groups.

Evidence from previous research should also be considered when interpreting these results. Madden et al's research comparing anatomy learning through VR, desktop and hands-on modalities suggests VR technology may not be sufficiently developed to provide conditions for improved learning:

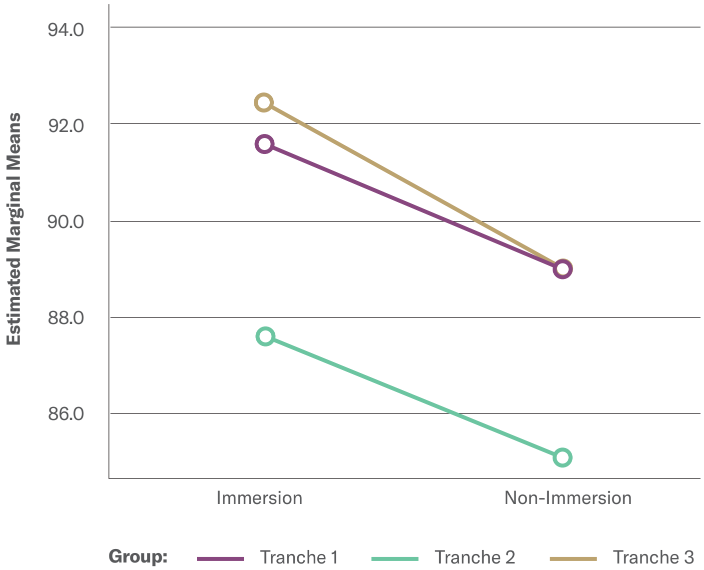
> *While VR technology has advanced rapidly, it is still not ideal. Control responsiveness, motion sickness, limited resolution and field of view are all technological obstacles that can still break immersion and distract from learning using today's equipment.*[7]

While Madden et al's findings are a couple of years old and advancements in VR technologies are likely, this evidence suggests that VR may not be sufficiently sophisticated modality to impact learning.

[7] Madden J, Pandita S, Schuldt JP, Kim B, S. Won A, Holmes N.G. (2020) Ready student one: Exploring the predictors of student learning in virtual reality. PLoS ONE 15(3): p. 19.

Group Composition

This graph compares the Tranche 1, 2 and 3 exam mean (average) scores for pilot and comparison groups.



Mean (average) scores for Tranche 1 and 3 exams were within a similar range. For reasons that remain unclear, the mean scores for both pilot and comparison groups on the Tranche 2 exam were lower.

Regardless of exam, the pilot (immersion) group participants scored higher, on average, than did their counterparts in the comparison (non-immersive) group. This suggests the pilot group would have been more likely to score higher on the Tranche 3 exam even if they had not had access to the VR experiences in Module 11.

B. Findings: Trainee Pre-Survey

In addition to comparing test and exam results from participants in pilot and comparison groups, a pre and post survey was completed to capture participants' possible change in knowledge and confidence over time. The post-survey includes additional questions about participants experience in the training. This includes separate questions for those in the pilot (immersive) and comparison (non-immersive) groups.

1. Pre-Survey Findings

- There are a total of 56 participants, 28 in both the pilot and comparison groups
- A total of 52 participant pre-surveys were completed, 27 from the pilot group and 25 from the comparison group
- A post-survey was developed and administered between April 12 and June 1, 2022, after Tranche 3 exams were completed

There was no significance between the mean scores of pilot and comparison groups in any areas of knowledge or confidence. This is a possible indicator that the groups are comparable in terms of their understanding of the role, knowledge and tasks of a composite technician.

In terms of both knowledge and confidence there are a number of areas where the pre mean score for both groups was high. This indicates a possible ceiling effect for these areas. As a result, there might not be much change in knowledge or confidence from the beginning to the end of the course, as participants came into the training with a high level of knowledge or confidence in particular areas.

C. Findings: Trainee Interviews and Post Survey

Interviews with trainees focused on the value-added of including VR experiences in the final Tranche of the COAST Composite Technician Training Program. Only those who accessed VR experiences were interviewed. This included participants from three companies.

Interview findings synthesized around successes and challenges associated with trainees VR experiences. Furthermore, trainees were asked their opinions regarding where they felt VR could provide value in aerospace training.

Trainees: VR success and challenges check list

SUCCESSES

- Enjoyment of the VR experience
- A less stressful experience
- Less risk
- Opportunities to make mistakes
- Appeals to visual learners
- Appeals to kinaesthetic learners

CHALLENGES

- More robust orientation materials & experiences
- Access and getting started
- Content in need of refinement & increased accuracy
- Technical issues
- Technology not sufficiently developed for precision required

1. What Worked Well

Enjoyment:

"I enjoyed it. It was interesting."

"It was fun, but it didn't really teach them anything."

"It was my first experience with virtual reality and I found it to be really fun…"

Less Risk and Stress:

"I think the hands-on is important, either physically [real world] or in VR. It is a more risk-free way of getting the same out of it."

"It was a lot more relaxed because [they] were not on the floor and are safe."

Opportunities to Make Mistakes:

"Often the mistakes are where the experience is best…if [trainees] are able to make mistakes and get 'messy' in VR, there is more assurance that this is learned."

"You could go back and try something before you had to do it for real."

"It was very helpful to practice on the VR headsets."

Good for Visual and Kinesthetic Learners:

"It [VR] can be helpful for lots of people who are more hands-on types of people…getting more out of trying the steps rather than just looking at a video."

What Worked Well: Analysis of successes focus on the opportunities for repetition and learning from mistakes was valued. Simulation appears to have created a less stressful situation where individuals could recover from errors without harm or waste. Training should consider the best ways of appealing to visual and kinesthetic learners, and VR may be a way of addressing the needs of these learners. Plus, some found it fun and enjoyable.

When considering VR in aerospace training consider….

- Allowing for opportunities for repetition
- Creating VR experiences that are hands-on and allow individuals to move

2. What Trainees Learned

The post-survey asked trainees what was the most important thing they learned during the course. Responses included:

"To make sure you have a clean place to work."

"I learned of many different aspects in comparison of what I do on a daily basis."

"The other type of composite bonding in other plants."

"Different ways of doing things."

"How important quality is throughout the processes, and how many little details and in each process."

"It helped me better my skills."

3. Challenges Encountered

Insufficient Orientation:

"The manual was not helpful."

"We didn't get anything written."

"I would have liked to have copies of the modules for future reference."

"If I had the time to properly test it before using it in class, it would have been even better."

"The orientation was like, 'this is a joystick and this is what it does'...It was too vague and it didn't help. The training was not appropriate to using the game itself [VR experiences]. It did not show how to use the device during the simulation."

Accessing the VR Experiences:

"There were some bumps with accessing the VR and...having to re-start. When using the headset, people lost interest because they were getting stuck on the first thing. Some didn't complete the training because of these complications.

Need for Content Refinement:

"Some content needed refinement to be most relevant. Some was not 100% accurate."[8]

"There were times when I was stuck and wasn't sure what to do next."

Technical Issues:

"There were some technical issues when using the hand controls, mainly how to pick up things when they were dropped."

"...difficulties in navigating and walking around."

More Developed Technology:

"VR experiences are cool or fun. I feel it needs to be developed a lot more to be educational...I don't believe that VR will be a means to train someone to become proficient in an activity [specialized technical training]."

Challenges Encountered: Analysis of challenges encountered focussed on insufficient testing, piloting and orientation. It appears that video orientation materials would be helpful. These need to go beyond explaining the what each part of the equipment does, to coaching regarding how these will be used during the VR experiences. Testing and piloting by non-experienced users will help ensure VR experiences are easy to follow, instructions are well understood and unforeseen technical issues are addressed.

When considering VR in aerospace training consider....

- Ensure appropriate orientation materials and opportunities are developed and provided
- Ensure testing by non-experienced VR users ensure detection of issues
- Lead time is needed for development and testing

4. Moving Forward

Those interviewed identified where they believed VR would add value to aerospace training. There was some doubt regarding the effectiveness of VR in training to the level of precision required in undertaking aerospace production competencies. However, VR was believed to be a good tool to create awareness of what is needed to perform certain tasks:

"VR cannot replace the practical and hands on, even if you have the best simulation. I don't believe that VR will be the means to train someone to become proficient in an activity. It can create awareness [of what is needed] but not proficiency."

Because of VR's strength in providing awareness, those interviewed believed that it could be used to orient new hires, as well as increase the understanding of the role of others within aerospace design and production: "I feel this course is better suited for new employees to composite bonding." It could create efficiencies by having designers and engineers understand the challenges encountered on the shop floor, as well as for those involved in production to know more about why aspects of production are engineered as they are.

[8] Note that three processes were covered within the program. Not all companies perform the same processes.

4

Key Informant Findings

In order to build on the sector knowledge regarding XR in aerospace technical training from the Evidence Synthesis, telephone interviews were undertaken with two groups – companies whose employees are participating in the COAST Composite Technician Training program and other key informants in the aerospace sector in Canada. Individuals were identified as key stakeholders by DAIR and OAC. A total of 13 interviews were undertaken between November 30, 2021 and January 25, 2022.

1. Aerospace Sector Training Needs

Those involved in the aerospace sector spoke of challenges in finding a trained and capable workforce. Reasons provided for this challenge focused on pre-service training and how this was not sufficiently “flexible to meet the needs” nor efficient enough to “…get people through the system.” College training programs were described as not up-to-date with the skills and competencies needed for industry and constrained by programming costs in acquiring equipment and skilled trainers.

One key information spoke of how XR in aerospace technical training could be a way of capturing collective knowledge of those leaving the sector:

> *“It could be used to crystalize knowledge. Some [long-serving] staff are retiring and knowledge not being lost. Through [creating] their avatar and voice being recorded, all the motion the future student can shadow [using XR]. Their knowledge is now under dust in [procedural] manuals.”*

In their words:

“Everyone is having difficulty hiring.”

“Supply doesn’t meet the demand – more skill sets are required in the workplace and the schools can’t produce them quick enough.”

Ensuring companies and industry do not lose the collective knowledge and understanding within an aging workforce indicates a possible niche for including XR in aerospace technical training, possibly most applicably in onboarding new hires.

2. XR in Aerospace Technical Training

Make It Real

Key informants agreed that aerospace technical training requires precise training situations and scenarios that mirror shop floor experience as closely as possible. The importance of making XR training experiences as close to shop floor roles and tasks was identified as a factor in the success of using these technologies in aerospace training. XR’s value as a learning tool was believed to increase the closer virtual experiences were to what would actually happen on the shop floor:

> *If you are going to be teaching a person a task, [it] has to be as real as possible. We know this in other areas like sports. I could show you a video about how to play hockey and that would help, but to get on the ice if you want to learn how to play hockey. It is same in aerospace…Visual is critical but then there is the tactile and the ergonomic. People are different sizes so they perform differently…It [XR technical training] should have the same look, touch, feel.*

While key informants spoke with one voice regarding the need to make the XR experiences in technical training as ‘real’ as possible, this did not mean they viewed these technologies as a replacement for other learning modalities: “The real thing is still best, but automation will help.” Another individual continued, stating “…automation is good at ditch digging [doing unskilled work], but when it comes to fine tuning, the human is best and always will be.” Despite gains in the ‘realism’ of XR technologies, key informants stated they believed automation of learning, irrespective of technology would not replace human-led training.

Flattening the Learning Curve

There was little doubt that the learning curve for those on aerospace shop floors, be it production or maintenance, is steep and therefore costly. Some key informants spoke about how XR has potential to flatten that curve by making training more accessible, shortening the time away from the production line, and supporting learner skills and confidence once they transition to the shop floor. As mentioned by one individual:

New products [aircrafts] are developed and you have a steep curve. How do you handle the learning curve? When you make the first one and subsequent takes less time. But everyone needs to learn what to do. That is the importance to learning and adapting quicker. Then, there can be changes to optimize such as reducing the weight. So now you have upskilling, and you go back up the learning curve, and hopefully back down quicker if you have good training…Now your aircraft is a success and you need more people and have to train them…Or, an aircraft has about a thirty-year lifespan, and demand starts to decline. You have this workforce and you need to re-deploy their knowledge, so that's more learning. XR can help to train folks and that's the big thing.

Key informants believed that XR could be a valuable tool in making the learning curve less steep. This could lead to trainees making it the shop floor sooner and/or being better prepared when they do, when compared with reading a manual or taking a tour of a facility. The possibility of trainees having greater confidence was also raised: "…increased confidence in doing a task. When people are comfortable they perform at a better rate."

Generally, informants felt the value of XR in aerospace technical training remained in getting trainees 'up to speed' faster and creating a more flexible workforce: "They are better prepared when they hit the shop floor for the first time." Another individual explained: "Visual and muscle memory will be triggered because of using this technology [when you get to the shop floor]." While this was not in doubt in the minds of many informants, this belief was based on XR experiences that were as close to 'real life' as possible.

How Does XR Impact Learning?

One individual spoke of the possible increase in student focus when working in VR. With VR "…you can only see what is in front of you, so your retention is impacted because that is all you see." While this key informant points out the VR can decrease distractions from extraneous stimuli, focus is only one aspect of recall/retention that was outlined in the evidence synthesis.

Particularly, key informants identified particular areas of strength where XR could be leveraged within aerospace, including:

- Learning Repetitive Tasks: "Repetitive tasks are prone to error. It is like driving a car. You don't think about what you do. If you didn't put something in the right spot, you can clear up a potential error."
- Procedural learning: "…understand the sequences…understand fitting a to b before doing c."
- Previewing: "VR gives them a good look on certain things, like taking an engine apart. It gives you a good knowledge of taking things apart and reassemble them.
- "I think with maybe the younger generations that are much more versatile in using computer applications. I can see the benefit for those generations."

Digital Campus

"Having a digital campus would be the first step in creating the ecosystem…a place where people could go and train…this could be deployed and scaled."

In College-based Training

It was clear that those involved in the aerospace industry felt that pre-service training in post-secondary institutions struggled to provide relevant learning experiences for students and in sufficient numbers to satisfy labour demands.

Key informants pointed out that the creation of a digital learning 'campus,' where XR could be incorporated could expand the reach of college-based aerospace training by making it accessible to those who cannot physically attend a college. Recently because of the COVID-19 pandemic, learning institutions and many other sectors have seen the challenges of place-based learning. What role would XR technologies play in a digit campus, where students could access 'almost hands-on experiences?' The advent of 5G, GSP training could support training through a metaverse.

The possibility of using XR in aerospace technical training within a digital campus was not without challenges, including a hesitancy on the part of trainers and training institutions, working across silos and navigating proprietary information. However, one key informant explained these could be mitigated through the creation of a consortium committed to creating a digital campus.

In Industry-based Training

While many spoke of the potential of XR to create smoother sailing to the shop floor, this was seen more as an addition or refinement of currently learning modalities. This was not seen as a replacement for mentoring/learning on the shop floor, rather as a way of making that happen more efficiently: "Newer aircraft with 3D models are geometrically it is very realistic. But then drilling a hole, just doing it virtually doesn't mean they can do it on the shop floor. Immersive technology [in training] is just getting them ready for the shop floor."

Key informants believed XR could enhance industry-based training. More specifically, one individual mentioned that using XR in industry-based training would be particularly helpful in upskilling current employees.

VR training would be great for technicians in the field. Say manufacturers have designed a totally different type of engine. Technicians have the experience of taking an engine apart, but this is something new that is coming down the pipeline.

Again, this related to possibility of getting employees to be more efficient once they get to the shop floor. In terms of learning, this is less about teaching the fundamentals of how to take an engine apart, rather it is upskilling the current workforce on changes to practice.

"Tools and technology are powerful and adaptable enough, but who creates the content will be the biggest factor. The companies have to be involved. Industrial experts and learning experts, Transport Canada policy people [have to be] all around the table to get the best out of it [and]validate all the pieces and all the product. The tool itself won't do it."

Furthermore, XR in industry-based training was believed to have the potential to create a more flexible workforce: "Digital has to be part of it [training]. No teacher can be available all the time, and students can learn more at their own pace." Including XR has the potential to all for more individuals to be trained more effectively without disrupting production/maintenance to the same degree. The key informant spoke to the possibility of using XR to familiarize those not involved in a specific task with the intricacies of particular tasks:

Engineers get closer information of the real product on a day to day. Tactical learning advisors are not there on the day to day...[XR learning experiences] ensures that the training is relevant and accessibility to the information visually that is powerful to the whole industry.

However, key informants also cautioned that training of any sort, irrespective of training modality, depends on who is creating it. They spoke of the importance of ensuring principles of sound pedagogy and adherence to adult learning principles. In addition, the success of any industry-based training hinged upon meeting the needs of all involved – trainees/learners, companies, sector organizations and regulators. The inclusion of XR alone was not viewed as sufficient to ensure a quality learning experience or to satisfy the industry's need for technical training.

3. Challenges to the Inclusion of XR in Training

Shifting the Paradigm

The inclusion of XR experiences in aerospace technical training would require learning content providers to shift from the current paradigm of two-dimensional online learning modalities to one which complements and takes advantage of what XR has to offer. Key informants spoke of how this will require a paradigm shift and moving away from the relative comfort of online learning:

"Today it is easy to do Powerpoint or e-learning using stock pictures. In 2D we know everything and how to create content. Shift in paradigm that needs to be build [to] import 3D objects. This is highly specialized, the kind that you need to work with is not available on internet. Making the 3D object requires data and digital twin."

Although what is needed to ensure a quality XR experience is not readily available, the capacity to build this is currently available. However, ensuring this is done to the standard of creating the 'as close to real world as possible' may mean that learning content creators will need to 'build' what is needed: "The bottleneck is in the creation of quality data (raw material) to make a quality XR experience." The use of stock three-dimensional materials is not yet available, adding to the time and cost of production of quality XR experiences. While this may not yet be sufficiently developed, as the XR industry grows, this will likely become less of a challenge.

Addressing Hesitancy

XR is a new and growing technology, and with anything new brings hesitancy of adoption. A number of industry key informants spoke of the aerospace industry as risk-averse, which often breeds hesitancy in the adoption of new technologies and processes. As expressed above, key informants believed that time and credible evidence of the possible impact of XR on aerospace technical training will help decrease hesitancy.

Nevertheless, there are some specific hesitancies to the adoption of XR in aerospace training that surfaced during interviews. These included hesitancy in sharing information viewed as proprietary and that of regulators. Key informants believed that the future of XR in aerospace technical training hinged on creating quality content that was relevant, highly realistic and that flattened the learning curve. In order to accomplish these goals, participation from companies, sector organizations and regulators was important. The hesitancy of companies to share information they considered proprietary was identified as a stumbling block. This was not seen as unsurmountable, provided trusting partnerships could be forged: "…bringing together a number of companies. They have governance rules and are taught not to share proprietary information. But, let's not make it 'everything is a secret.' We're not stealing your documentation."

Propriety Information

"In our experience, no matter how much companies want to work together, when it comes down to it, they don't. It is their competitive edge and they don't really want to share that."

Regulators, notably Transport Canada, were also described as hesitant regarding the adoption of new technologies. Industry informants spoke of current challenges with the regulator that have surfaced as a result of changes required by the COVID-19 pandemic:

> *With AME's [Airplane Maintenance Engineers]… hands-on is needed for Transport Canada certification. Just recently because of COVID, they just recently considering remote learning. Before it had to be face to face with instructor. Time will tell about reconsideration of this.*

Regulators are charged with ensuring safety, not only of the products produced, but also that those who are undertaking this work have the necessary competencies to undertake production to the highest level. It is understandable that this perspective could be at odds with industry, whose goals for including XR in training is to 'flatten the learning curve' and get employees to a level of competency on the shop floor as quickly and efficiently as possible. It is not surprising these two perspectives could, at times, be incompatible.

As previously mentioned, hesitancy among a number of organizations would likely be alleviated by providing strong and credible evidence of the effectiveness of XR as a training modality, focusing on competency-based training and ensuring all parties (educators, XR content creators, companies, sector organizations and regulators) are consulted and involved.

Regulator Hesitancy

"Transport Canada…will it accept it? If we get them to focus on the outcomes at the end of the program…is the student able to do all the things? Do they have the knowledge to do what they need to do? Getting Transport Canada to focus on this is a challenge."

Development Challenges

Key informants outlined a number of challenges regarding the development of XR training experiences for aerospace. These focused on two particular areas:

- Creating a quality XR learning experience and the cost this entails
- Creating XR learning experiences that involve all of the 'touch/feel,' movement and environmental constraints that truly mimic 'real world' realities of working on the shop floor

As previously mentioned, key informants agreed that XR's value in learning experiences lay in its ability to create a quality learning experience that was as close to 'real life' as possible. This was believed to 'flatten the learning curve,' get trainees to the shop floor faster and therefore impact production. In the current market in Canada, achieving these goals was time consuming and costly.

While the cost of user equipment, such as VR head-mounted display equipment, is decreasing, the cost of developing the what is needed to create quality learning experiences. This includes having the assets needed:

You need a full digital model of the vehicle and the production environment.

You need full 3D and most facilities and tooling are not 3D. It depends on when the aircraft is designed and built...There's lots to put together before the immersive learning can take place.

While two-dimensional assets are readily available for online training, three-dimensional assets are not. As one individual described: "Infrastructure for training, if you don't have it, you can only do general training." This is not likely to meet the standard of realism advocated for quality learning experiences. Even if 'stock' 3D assets are used, key informants cautioned that what is needed to get them to 'perform' in ways that are realistic requires "...lots of work behind the scene..." contributing to the time and cost of production. Those having the knowledge and skills to create quality XR "...who can take the knowledge base of aerospace training and VR technology..." were described as 'hard to find.'

> **Quality XR is Costly**
>
> **"I think the challenges are the cost of equipment and development costs, for small and medium-sized companies. We've developed training that is online...The stuff that was engaging and interesting was not cheap."**

> **Quality XR Requires Tactile Precision**
>
> **"The weight of something; how it moves; the resistance. In VR you don't feel the resistance. This is the difference to understanding the hand skill to understanding operations."**

While key informants believed that XR could definitely contribute to aerospace technical training, many outlined how the technology does not currently have the capacity to deliver a quality, real-world experience for all training situations. One individual cautioned that the precision and 'having no room for error' needed in many aerospace technical competencies meant that XR was not a suitable replacement for hands-on training in the classroom or the shop floor:

"The real experience is to have the tool in their hand. How much force it takes. VR is good. It's got its' positives in certain areas, but when it comes to the actual area and skills, I don't think it would give you the same. The students really need that feel.

For many, creating a real-world in XR training experience requires the involvement of all senses. This was described as costly at best, and near impossible at worst, given the current evolution of XR technology. Key informants believed that XR has a place in aerospace technical training, but possibly in more generalized areas until the technology becomes more sophisticated. At present, XR was viewed as insufficiently developed to produce a multi-sensory experience needed to highly skilled technical training.

4. XR and Increasing Capacity

Key informants were asked their views regarding how XR in aerospace technical training could increase the capacity of individual trainees/employees, employers and the sector in general. Individuals stressed that their responses were based on the assumption that 'this is done right,' as outlined above. They emphasized that the possibilities of XR's value added were dependent on creating quality learning environments: "The tool itself [XR] will not do it."

Individual Trainees/Employees

When asked how XR will increase the capacity of individual trainees/employees, key informants spoke of increasing confidence in new skills and "...getting up to speed properly." An increased reach or inclusion was also articulated as increasing the capacity of some individuals in aerospace:

> *I assume it would allow for a more inclusive environment. There are a limited number of colleges that are teaching these programs. It would be more accessible to remote and northern colleges, those who don't have the equipment*

Some highlighted a possible distinction between newer and more senior employees. Younger employees were believed to have a higher likelihood of comfort with XR technologies. Other pointed out that XR might be well-suited to upskilling more senior employees, those that bring a rich background of experience from the shop floor and only require upgrading or knowledge of a new product or process.

Generally, those interviewed believed XR could be a valuable tool for employers. It could increase their confidence in hiring and training employees at a higher level. The challenge of recruiting and retaining skilled workers has already been discussed: "[They have] business opportunities they can't fill because they can't find the workers." Advantages for employers included being able to have a stronger voice in training content and delivery, increased ability to provide workplace training and providing for upskilling.

> **XR and Workplace Training**
>
> **"Not leaving the workplace; financially it makes a lot more sense. [With] in-house training, employers have better control over that training."**

XR was believed to support the possibility of employers being able to provide more workplace training. This was viewed as having a number of advantages. First, key informants spoke of the possibility that employers could have more voice in training content and learning opportunities: "Employers can also control what training each individual would need." Another individual mentioned that if this were done right, it could directly meet the needs of industry. With the growth of XR and the commensurate decrease in production costs, the potential for being able to tailor training to the specifics of the workplace might allow for what was described as 'boutique' training, where "...it is modified to need their specific needs and has the potential to get what they need out of the students." While this was expressed by some key informants as increasing the capacity of employers, a caution from the current pilot of the Composite Technician Training Program is warranted.[9]

In addition to having more control over training content and learning, XR may increase employers' capacity to provide learning experience onsite, thus reducing time 'off the shop floor:' "Not having to leave is a cost saving in the long run...not sending everyone off to a college or elsewhere (15 to 20 employees). XR helps to train remotely, [particularly] if there is no schooling nearby." Key informants stressed the potential for XR to provide distance learning and on-site opportunities would increase the capacity of employers to have a trained and efficient workforce, thus creating an adaptive workforce is an efficient workforce. Finally, one individual pointed out: "Upskilling on their own instead of waiting for a class. You can't have one person in a class. VR would be good in this situation."

XR's potential to support upskilling was also mentioned as increasing the capacity of employers:

> *Companies will have a stronger ability to introduce new technology into the workforce by creating less down time for change processes and higher reliability. If you get a new product line or new machine, this [XR experiences in training] could help you pivot and upskill faster and give you a competitive edge.*

One key informant explained that car manufacturers were using XR technology in this way to upskill mechanics in dealerships on new products.

[9] Due to time and cost constraints, the Composite Technician Training Program was unable to develop VR training experiences suitable for one of the companies who wished to participate.

The Aerospace Sector

When it came to suggesting where including XR in aerospace technical training might increase the capacity of the aerospace sector as a whole, key informants mentioned its' potential role in recruiting new individuals, ensuring collective knowledge is preserved and providing better pre-service training environments.

- Attracting new individuals to the sector: "Might motivate those to understand the complexity of the field and where you can go."
- Recruiting new individuals to the sector: "Transferability across sectors…pulling in employees from other sectors."
- Capturing knowledge: "There is an aging population in the workforce. They can do a lot of things that younger ones take some time to get there."
- Enhancing pre-service training: "Any school could have access to ten-million-dollar GE engine if it is available in VR. The front-end cost would be significant but if OEMs [Operational Equipment Manufacturers] endorse VR to fix parts, can also be used to training next generation of workforce and not have to have workers in the classroom at the same time.

5. Where Might XR be Most Beneficial?

Key informants were clear when they outlined the areas where they felt XR has the potential to impact aerospace technical training. They spoke of how this should be an evidence-based approach informed by comprehensive data and analysis.

One key informant suggested an industry workforce demand approach. Using analysis of work force (current and future demand), what are the areas where there are the largest workforce numbers? According to one key informant: "The majority of workers are assembly, so target assembly first, as they make up the largest part of the workforce. You would then break down to structural and systems (fuel, electronic, hydraulic). After that, quality inspection and functional test make up about 12% to 15% of assembly of workforce."

When asked where they believed the inclusion of XR technologies in aerospace technical training would be most beneficial, informants listed a number of areas, including:

- ✔ Safety Training - "Allowing for all the checks and balances in a virtual world." "The student walked around [virtually] and saw hazards. They had to get the hazards and identify the problem. They passed the course if they found them all."
- ✔ Emergency Response Management – "Anything that goes wrong on the shop floor. It [XR] can simulate that, plan for it and train for it."
- ✔ Foreign Object Debris – What happens when FOD happens and how it can be avoided.
- ✔ Inspection – Training inspectors and getting others to understand inspection: "Modules that ensure they are doing the inspection correctly."
- ✔ Non-Destructive Testing – This would cross into many roles, as a demonstration of the consequence of errors that are made in production and maintenance.
- ✔ Sealing
- ✔ Sheet mold composites – "VR would be really good, as students wouldn't be exposed to chemicals, dust, etc."
- ✔ Procedural – do A and B before C – and logistical processes
- ✔ Training others – getting the team to understand what others do and why. Some don't need to have the sophistication of training an AME in certain precise operations, but might be suitable for engineers to understand the experience of those doing things on the shop floor.
- ✔ Diagnostic – what's wrong and how to fix it - review the potential defects. Electrical and engine problems were highlighted. This already used in the automotive industry.
- ✔ Repetitive tasks – these are prone to error because don't think about what you do. Demonstrating the clear up a potential error in repetition. Mitigating against this type of error.
- ✔ Upskilling on new processes (in-service training)
- ✔ Group training – "Used to send people away for training on their own. That's not how others train. Sports teams and the military send a group for training [to] learn and train together. We could send production teams to train together. This is where XR could come in."

5

Bringing it all Together

This final chapter weaves together conclusions drawn from all findings, qualitative and quantitative. This is framed by the central research question: Does integrating immersive technologies enhance aerospace technical training and lead to better learning outcomes?

It is followed by a discussion on how these conclusions can point a way forward in the inclusion of XR in aerospace technical training.

A. Conclusions from Findings

1. Evidence Synthesis: Don't Believe Everything You Read

Conclusions from the Evidence Synthesis are outlined at the end of Chapter 2, however a cautionary note regarding the need to scrutinize evidence into XR is warranted. As mentioned, the available information about XR falls into two general categories - academic sources such as peer reviewed journals and industry sources, such as trade journals and reports produced by specific companies and/or sector associations. While these industry sources provide applied and 'real world' information, their goal is largely marketing and does not stand up to strong evidential scrutiny. As a result, this creates a landscape of information about XR that is biased and not based on credible evidence. Those considering incorporating XR into their learning and work environment are reminded to be discriminating in their choice of information upon which they base decisions.

2. No Significant Difference: What Does This Really Mean?

Exam scores at the end of each Tranche of training tell the same story, irrespective of Tranche or group (table below).

On average, participants scored high irrespective of group (pilot or comparison) and the difference in average scores between pilot and comparison groups were similar. There was no statistically significant difference between groups for the Tranche 1 and 2 exams. As stated previously, there was a significant difference between groups in Tranche 3 scores, however the small sample size that was not normally distributed means that a major assumption was violated. The reader is therefore cautioned when interpreting the statistical significant difference in Tranche 3.

Returning to the research question, the findings from exam scores suggest the research question was not upheld, namely that integrating two VR experiences into Module 11 of the Coast Composite Technician Training Program did not lead to better learning outcomes. This indicates that there is no discernable learning effect of integrating VR into this training course.

The New Burning Question: Why Might This Be?

With findings such as this, it is important to highlight possible reasons. The first is the most obvious, that including VR, as it was executed in this instance, did not affect outcomes for learners. In other words, the VR or learning modality itself does not impact learning. However, other areas of the research suggest there are other possibilities that explain this finding. These are outlined in the 'Limitations' Section of Chapter 1, although worth discussing here.

It is possible that no significant difference was detected in Tranche 3 exams because the intervention itself (the inclusion of VR experiences in Module 11) was too 'low dosage.' This suggests the VR experiences were not sufficiently sustained or frequent to produce a detectable effect. This would be consistent with findings from the evidence synthesis.

Descriptive and Inferential Statistics	Tranche 1 Exam	Tranche 2 Exam	Tranche 3 Exam
Mean (Average) Score	90.6%	87.6%	90.1%
Median (Middle) Score	92.0%	88.6%	90.2%
Mode (Most Frequent) Score	93.0%	94.0%	94.1%
Range of Scores	71% to 98%	66% to 100%	80% to 96%
Mean Difference	2.7%	3.9%	3.5%
Statistical Significance (p-value)	p=.12	p=.12	p=.047

Supposing a statistically significant difference does exist, there may also be reasons why this was not detected in the current research:

- The assessments could not detect the difference. Because there was not time for the assessments to be piloted with respect to the key research question, it is not possible to know if they measured what they intended to measure. The questions and indicators may not have been sufficiently precise or granular to detect a difference. Steps toward ensuring the validity and reliability of assessments, with respect to the specific research question, is a future consideration for similar programs. The potential is that the addition or granularity of questions could help detect a difference in the training outcomes of the two groups.
- Because a passing grade was 65%, exam findings data sets for all exams are skewed right. This contributes to a ceiling effect, where the possible range of scores is only 30% rather than the more traditional 50%. This may have affected the ability to show significant differences in aggregated scores by group.
- Group size dwindled over the course of the training and became small by Tranche 3 where VR experiences were included for those in the pilot group. As previously mentioned, statistical significance is volatile to sample size, with small groups being less likely to detect a statistically significant difference.
- Trainees were chosen by the companies and sorted by the research team into pilot and comparison groups according to a number of criteria. Each group included individuals who were already working as composite technicians and some were even in supervisory and lead hand roles. It is possible that familiarity with the competencies required for the job (as all trainees were current employees receiving upskilling rather than new entrants) may have influenced the results.
- Although VR has been part of the technology landscape for some time, it can still be described as emergent. It is possible that no significant difference in learning outcomes was detected because this technology is not sufficiently sophisticated to mimic the real world realities of working on the composite shop floor to provide improved learning outcomes. Again, this is consistent with findings from the evidence synthesis.

Therefore, all that can be said conclusively from this research is that the VR experiences provided in Module 11 of the COAST Composite Technician Training program did not impact trainees learning.

3. Beyond Exam Scores: What Did Participants Say?

Multiple areas of inquiry and strains of evidence were used in this research to inform possible conclusions. Despite there being no difference in exam scores between those who had VR experiences and those who did not, pilot participants valued VR as part of the training because:

- It allowed for opportunities for repetition and learning from mistakes.
- VR created less stressful training environments where individuals could recover from errors without harm or waste.
- They valued the VR experience as fun and interesting.

These findings were supported by key informants and by research in the Evidence Synthesis.

4. Key Informants: Current Possibilities For XR

Key informants shared that there is a disconnect between current pre-service training (college and university training) in Canada and aerospace industry needs. They suggested that XR could be harnessed to:

- Attract young workers to the sector
- Update and improve pre-service training and in-service training in a way that is more effective and cost effective, including access to training in remote areas.
- Harness knowledge of an aging workforce who will be leaving the aerospace sector

5. Key Informants: What Is True Today May Change Tomorrow

Key informants, as well as some Evidence Synthesis sources, outlined challenges to the inclusion of XR in aerospace technical training. However, some of these might be mitigated by time. As previously mentioned, XR technologies are evolving quickly, meaning that some of the issues discussed in this report could change in future:

- Cost: The cost of equipment (VR headsets, etc.) will likely be mitigated in the future, although more research is required to determine if the cost of production will decrease. Evidence suggests creation of quality learning experience is one which is as close to 'the shop floor experience' as possible. While using 'stock' XR content may reduce production cost, caution in using material that is not the best suited to the creation of as real life as possible is advised.
- Economies of scale: The future of XR may hold economies of scale, however it is too soon for there to be strong and credible evidence for this. This does not mean those interested in incorporating XR in training should not go forward, only that choices need to be aware about scaling possibilities.
- Hesitancy: Time often brings with it a decrease in hesitancy of adoption of technologies. As more and more companies and industry actors have success with XR in technical training, hesitancy may decrease. However, there is a tendency in the sector not to share data and information that is viewed as proprietary, which may challenge the exchange of information about successes with XR.

B. Next Steps: A Roadmap for XR in Aerospace Training

From UP360

WHY XR?

Reasons why companies are investing in XR differ. XR has the potential to alter the way we communicate, work and train. However, it is important to understand the pros and cons of the technologies and what to consider when looking at investing in these new tools.

THE WAY WE COMMUNICATE

Limiting video conferencing calls; with XR, a headset is all you need to be in the same room as your friends and co-workers.

THE WAY WE WORK

Visualize data in new ways; accessing information anytime, anywhere without tying up your hands.

THE WAY WE LEARN

The potential for advanced training, including more realistic simulations of sophisticated and precise training tasks and activities.

VIRTUAL REALITY

The most common forms of virtual reality are...

360° Photo & Video or 3DOF VR

3DOF VR is a limited and low-level form of VR that requires inexpensive hardware to run. 3DOF VR is typically captured using a specialized VR camera designed for panoramic photo or video. The video can be viewed in VR or run on a phone or tablet outside of VR as a panoramic image. The most recognizable form of this is what you see on google street view; just imagine instead of using your mouse to look around you use your head while wearing a VR headset. Most 3DOF-only VR headsets are being phased out as stand-alone headsets become cheaper and more powerful.

Stand Alone VR - 6DOF

Stand-alone VR allows you to view 3DOF content along with more immersive and interactive 6DOF content. These headsets do not require an external computer to render the graphics; instead, they have an onboard GPU similar to a high-end smartphone. This type of VR is often limited in terms of how realistic you can make an experience because of the limited processing power. However, its most significant benefit is lower cost and portability compared to PC VR. Some examples of Stand Alone 6DOF VR headsets include Oculus Quest and the Pico Neo 3.

PC Based VR - 6DOF

PC VR offers the most powerful and immersive experiences you can get. These experiences leverage a headset tethered to a high-powered gaming PC or laptop to render the VR experience. These VR experiences can oftentimes look realistic and push the boundaries of what is possible in the virtual world. The pitfalls of PC VR are in its higher cost and lack of portability due to the external PC required to power it. Some examples of PC-Based VR headsets include Vive Pro 2 and Valve Index.

Our criteria for evaluating each technology

IMMERSIVENESS & QUALITY

On a scale of 1-5, 1 represents traditional learning techniques such as watching a video, looking at a photo or reading (very passive activities), whereas 5 represents learning by doing the real thing, one of the most hands-on and engaging ways to learn.

USABILITY & SCALABILITY

On a scale of 1-5, 1 represents technology that is not user-friendly and would require someone with a significant technical aptitude to operate like a 3D printer, while 5 represents technology that is easy to use and is ready to be deployed to the masses, like a smart phone.

COST & TIME OF RUNNING A PILOT

A general range for cost (in CDN) and time associated with developing and deploying a pilot with each technology. We will also make a note of any off-the-shelf software and its associated costs.

360° Photo & Video or 3DOF VR

How's it made?

3DOF VR is typically created using a specialized VR camera designed to capture panoramic photos or videos. These cameras leverage multiple lenses to shoot with no blind spots. The image is then stitched together in a way so it appears seamless when viewed in VR. Low-cost cameras that are point and shoot cost around $500, but will yield poor image quality that can be unwatchable in VR. Higher-end units can cost tens of thousands of dollars and are significantly more complex, often requiring a skilled operator and editor to work with the content.

The Pros

Straightforward use.

The hardware is affordable.

Scalability; the technology works on other types of devices with little effort needed to port it over.

The Cons

It may cause motion sickness.

Files can be very large, especially with higher-quality video.

Image quality is often grained and pixelated through a VR headset.

Here is how we rate the technology....

IMMERSIVENESS & QUALITY — 2 OF 5

Low Immersiveness & Low Quality

This type of VR has little interactivity. It's point-and-click interactions with the ability to look around. Additionally the images are also low quality, with most content lacking depth perception which causes photo and video distortion when seen in VR.

USABILITY & SCALABILITY — 4 OF 5

Ease of Use and Scalability

What it lacks in quality and immersivness, it makes up for in scalability and user-friendliness. Put the headset on and press play, and you are ready to go. It's also easy to mass deploy devices or send content to people to view with smartphones at home.

COST & TIME OF RUNNING A PILOT — LESS THAN $25K

Low Cost and Quick to Produce

This type of VR is still popular today in part because of its comparatively low cost. All you need is a VR camera, basic video and photo editing skills and off-the-shelf editing software, and you can produce and publish content.

Stand Alone VR - 6DOF VR

This type of VR is very similar to PC-Based VR. The only significant difference is in the hardware. Stand Alone VR headsets have an onboard GPU that's nearly as powerful as those found in high-end smartphones. This renders experiences with just the headset and controllers. Both types of hardware allow users to view 6DOF or 3DOF content.

The Pros

The hardware is significantly more affordable compared to PC VR. +/- $1000 per unit.

Without the need for a PC, the hardware is portable and can more easily be taken home by learners.

The Cons

There are significant limitations in the processing power of the headset. Experiences will be limited in fidelity and realism.

By default, the experience in the headset is not cast to an external display. This makes it hard for other participants or instructors to see what the learner is seeing.

Here is how we rate the technology....

IMMERSIVENESS & QUALITY — 3 OF 5

Highly Immersive & High Quality
This type of VR offers highly immersive 6DOF VR experiences and has improved quality when compared to 3DOF headsets. Compared to PC VR, however, the quality is significantly less due to the small onboard GPU that may create challenges with optimization.

USABILITY & SCALABILITY — 4 OF 5

Ease of Use and Scalability
A headset and controllers is all you need—making this one of the most scalable and easiest to use forms of XR on the market today. Take it home in a backpack or ship it to an employee in a small box.

COST & TIME OF RUNNING A PILOT — $100K AND UP

It can be costly to custom develop
Because of how this type of VR is created, along with potential optimization challenges, it can be costly to develop even a simple pilot for education and training.

PC Based VR - 6DOF VR

With PC VR, you can get the most lifelike VR experience currently available. These headsets use a PC with a more powerful GPU than the built-in smaller GPUs in standalone VR to render the experience. This enables high fidelity and lifelike simulations. Both types of 6DOF VR are typically created from the ground up using game programing software like Unity or Unreal Engine.

The Pros

You get the highest quality, most realistic VR experience possible.

Other participants and teachers can see what you see on the PC screen. This makes it easy for teachers to help and allows students to learn by watching.

The Cons

The hardware is more expensive due to the need for a PC. +/- $5000 per unit.

The setup is also less portable due to the need for a PC.

Here is how we rate the technology....

IMMERSIVENESS & QUALITY

4 OF 5

Highly Immersive & High Quality

PC VR is the most realistic VR experience currently available. This variety of VR provides rich, immersive interaction and high-quality graphics that is unmatched in other current VR or XR forms.

USABILITY & SCALABILITY

3 OF 5

Ease of Use and Scalability

This setup requires a PC or gaming laptop to run the simulation. It's easy to use while it's also easy to view what learners are experiencing. Plus it can still be portable if paired with a laptop.

COST & TIME OF RUNNING A PILOT

$100K AND UP

It can be costly to custom develop

Because of how this type of VR is created along with the optimization challenges, it can be costly to develop even a simple pilot for education and training. Costs of hardware may also be a barrier for smaller organizations.

A Real Life Case Study

The International Air Transport Association (IATA) faced a challenge of how to train employees effectively if they are unable to learn on-site by experiencing work in real-life situations. IATA needed to establish a training program to provide trainees with extensive classroom-based learning, mixed with shadowing experienced staff. While this gave trainees a thorough theoretical grounding, it did not give them a real sense of the work space, including the impacts of adrenaline, fear, their reactions and decision-making skills. Dimitrios Sansos, Senior Product Manager of Airport, Fuel & Ground Operations Training and Publications, expressed his concerns and identified VR as a solution:

"The most effective way to learn is through experience. In live operations, it's very difficult to show people what can go wrong and how you can mitigate. Everything is smooth when operations are running in a very safe way. You don't have the chance to show them what can go wrong... In the virtual environment, you can replicate error issues that we know exist in the industry and you can do it several times without affecting any real operations or any real equipment." (Duhon & Trevino, 2020)

IATA developed RAMPVR, a VR technology that replicates real-life, high-risk scenarios in which people can learn safely. Participants were placed in a variety of scenarios around operational issues such as foreign object debris and marshalling aircraft. In the marshalling module, trainees used VR controllers to perform the correct hand signals used on the tarmac. Using a neural network trained to understand these gestures, participants could signal to aircraft in VR and the aircraft would react as it would at the airport. This enabled a new level of immersion in the training scenario.

> **"Training using VR provided a faster route to competency development of trainees. Crews of trainees experienced a greater breadth of scenarios resulting in better-trained people at a reduced cost."**

Being fully compatible with IATA standards, this VR training was integrated into IATA's training program to complement its classroom-based learning. It has built-in metrics to track and monitor each participant's performance which is then fed to their overall training record. Training using VR provided a faster route to competency development of the trainees. Crews of trainees experienced a greater breadth of scenarios resulting in better trained people at a reduced cost. Training without risk of damage and the opportunity to practice multiple times without tying up expensive equipment were additional outcomes.

Stand Alone or PC-Based VR - 6DOF

Although there are a few pros and cons to stand alone vs. PC-based VR hardware, the general applications are similar.

THIS TECHNOLOGY IS WELL-SUITED TO:

Scenario-Based Training
Need to train someone on a scenario that can't be replicated in real life due to cost or safety concerns? 6DOF VR allows for the creation and implementation of any scenario without real-life consequences. Trainees can practice as many times as needed until they know how to complete a task safely. In these types of training scenarios, everything can be measured down to the smallest safety infraction.

Procedural Task Training
Need to teach someone a new procedure or process in manufacturing? 6DOF is one way to do that without wasting time or material. Use VR to get their skills and knowledge competencies up and reduce the amount of on-the-job training needed. This may help avoid costly mistakes.

Process Design & Improvement
Before building a new assembly line or plant, consider building and testing it in VR with real people. VR provides a chance to optimize the layout as well as reduce inefficiencies and ensure new processes are also designed with human ergonomics in mind. This may avoid unnecessary strain on employees.

Remote Learning & Collaboration
Allows people to feel like they are all in the same room. In this way, VR could be an effective means to teach and collaborate with others remotely.

THIS TECHNOLOGY IS NOT SUITABLE FOR:

Theory-Based Training
Things like mathematics or physics theory that are not procedural and highly theoretical can be costly to develop in VR. The more structured the experience, the easier it will be to create.

Social Skills Training
Character animation and natural voice processing in VR can be challenging. Although AI is rapidly evolving, the technology is not yet able to have life-like conversations with computer-generated characters.

Tactile, Fine Moter Skills
Some things cannot yet be replicated in the digital world. Tasks that take fine motor skills like turning a screwdriver or feeling the way a machine works are not a good use of the current technology.

AUGMENTED REALITY

The most common types of augmented reality are...

Marker Based AR

This type of AR uses a physical marker to trigger an AR experience. Markers can be a simple as a QR code, an image, object or even a face. When the camera recognizes the marker, it triggers and locks down the corresponding digital asset. That way the user can move the camera around while the asset stays fixed in place. Some of the most notable examples of this form of AR include face filters or traditional media AR experiences where a user points their camera at a photo, and it appears to come to life.

Location Based AR

This type of AR uses a geographical location or proximity tag that can sense the distance to a location, often times in combination with a marker to trigger an AR experience. Some of the most notable examples of this form of AR would be Google Maps.

AR experiences can come in different shapes and sizes. Though, fundamentally, every experience needs two things: a quality smartphone or tablet and a digital object. AR is the most simplistic form of XR as it leverages everyday devices.

Here is how we rate the technology....

IMMERSIVENESS & QUALITY — 3 OF 5

AR can be useful, but inconsistent

AR feels like looking through a window via a smartphone screen into an immersive world. That immersion is often limited by the screen size and can be inconsistent depending on what type of device is being used.

USABILITY & SCALABILITY — 4 OF 5

Ease of Use and Scalability

Since AR leverages existing consumer devices, it is very scalable. It's also relatively easy to use, typically requiring users to download an app and enable camera privileges, operating as a point-and-click experience.

COST & TIME OF RUNNING A PILOT — LESS THAN $50K

Custom can be costly but there are ways to save

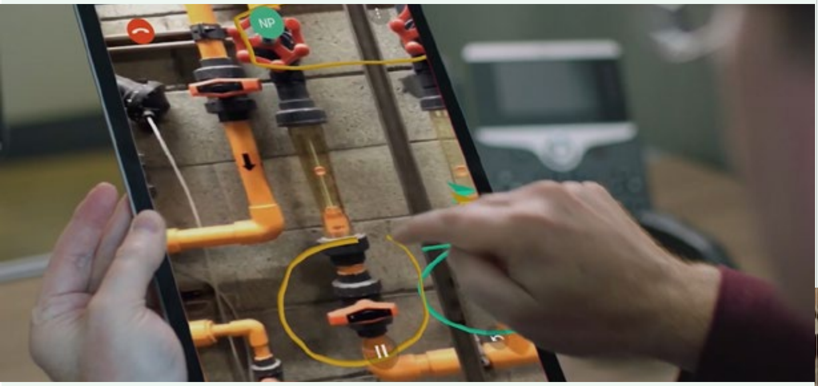
Custom developing an AR experience can be costly. However, this technology has been around for long enough that there are several off-the-shelf apps that can be affordable options.

AUGMENTED REALITY

If custom building an AR experince is out of budget or you want to explore off-the-shelf options, the following are currently available smartphone and tablet applications:

VUFORIA Chalk: Remote AR Collaboration

Vuforia Chalk turns a smartphone into a powerful, visual tech support tool. Once the app connects the user and a co-worker on a video call, the user's rear phone camera becomes a viewfinder to show exactly what they need help with. Both parties can then draw on the screen with AR chalk that works like visual annotations, allowing the user to find the right buttons, dials, and controls without relying solely on verbal descriptions.

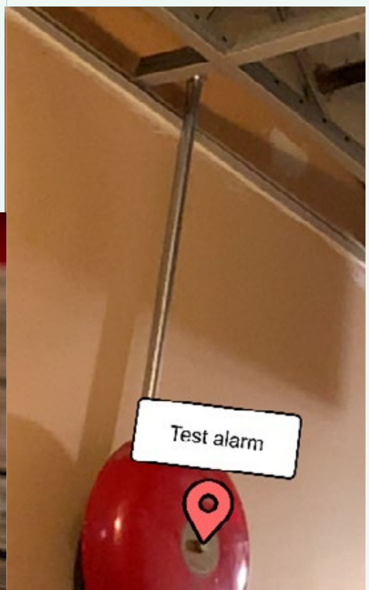


AUGmentecture: AR Viewing of AutoCAD Files

AUGmentecture is softwre that views complex 3D models on a mobile device in an AR format. With the help of the AUGmentecture plug-in, the user can seamlessly and securely upload 3D models and floor plans directly from Autodesk® Revit® to their AUG account to view later. AUGmentecture's goal is to make AR a day-to-day design communication and collaboration tool for architects, designers, and artists.

Placenotes: Creating AR Guides

Placenotes makes it simple to build practical AR experiences that can make the lives of on-site workers easier in the construction, maintenance, manufacturing and inspection industries. The app allows users to create and share AR guides to help a new employee get around or even help someone remember all the key items they need to inspect.



The Pros

AR is scalable as it leverages already owned consumer devices.

AR can be piloted more cheaply than other XR due to off-the-shelf apps.

Newer smartphones allow users to scan objects and rooms, which can be used to create simple, custom apps with little upfront investment.

The Cons

AR experiences can be inconsistent with older smartphones.

Not as interactive or immersive as other forms of XR.

A Real Life Case Study

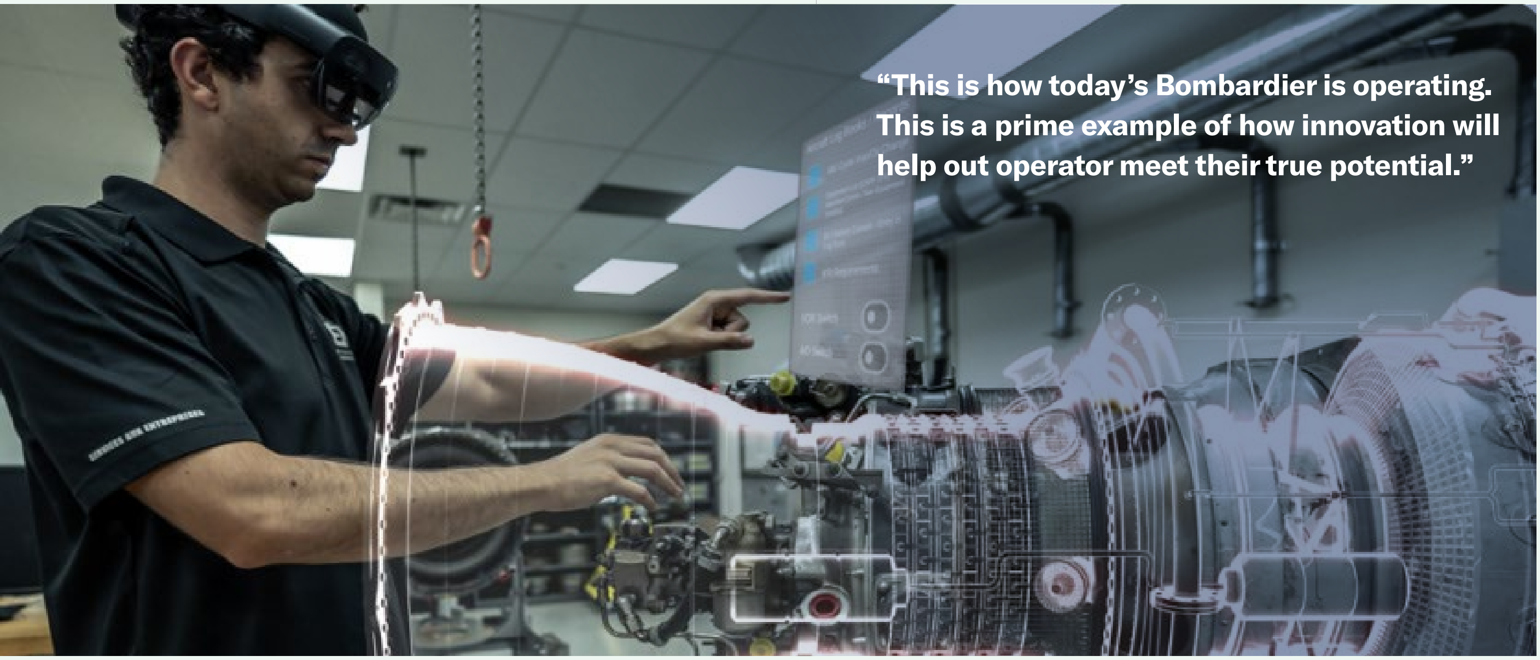
In 2020, Bombardier partnered with OVA and their StellarX platform, working to accelerate the quality inspection and repair process for composite components of an aircraft fuselage.

Inspection is a continuous process, and a key component is a visual inspection, but it is a process that can be cumbersome. Each defect must be individually located and verified by an operator.

By using a composite manufacturing robot to locate any possible defects and sending this information to an AR device, the operator was able to see the overlayed defects and be guided in their work. This was able to save time in the overall process, resulting in increased productivity.

Another real life AR case study can be found in Rolls Royce's customer facing use.

Using the smartphone application Librestream Onsight Connect, staff insert a data gathering probe into an aircraft engine and connect to a trainer from Rolls Royce, the customer engineer can be examine for faults remotely. Using smartphones, each can see and draw on the screen to highlight issues or areas of concern. This virtual presence has sped up inspections for companies and airlines, saving time and money.



> **"This is how today's Bombardier is operating. This is a prime example of how innovation will help out operator meet their true potential."**

THIS TECHNOLOGY IS WELL-SUITED TO:

Visualizing Objects in the Real World
One of the best use cases of AR is seeing what objects might look like in the real world before they are actually put there such as equipment and displays.

Equipment Based Training
AR can provide a way to train someone on a piece of equipment or machinery without needing to study the blueprints. Utilizing this technology can instead allow them to see and interact with complex machinery at scale or even as a tabletop model.

THIS TECHNOLOGY IS NOT SUITABLE FOR:

Interactive Training
Any training that is highly interactive and would require users to do things like select, use tools or grab and place multiple parts would be challenging to accomplish in AR.

Environment Based Training
Scenarios that require a user to navigate a digital environment would be nearly impossible in AR since it's intended to leverage the environment currently around the user. It's best used in object-centred experiences that don't need an environment.

MIXED REALITY

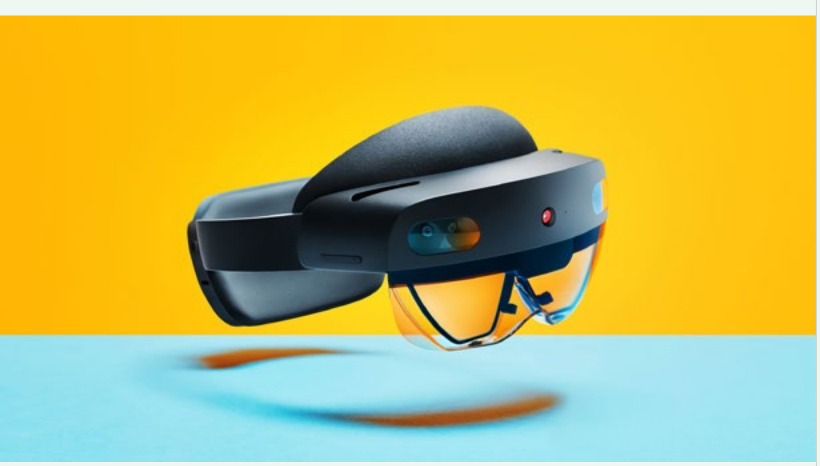
The most common types of mixed reality are...

Smart Glasses - Simple Display

Simple display smart glasses such as Google Glass enable an extremely basic form of mixed reality. These glasses can sometimes see the world around the user, but are limited to displaying basic text or digital information within the field of view.

High-End Mixed Reality - Full Display

High-end mixed reality devices are powerful and project full-color holographic images into the field of view. These devices are outfitted with enough sensors to give the device a basic understanding of the world around the user. Digital objects can be placed on tables and knocked off by a user pushing them with their hand. These types of devices blend the digital and real-world together, making it difficult for the user to tell what is real and what is digital.



Although there are many devices on the market advertising as mixed reality headsets, only a few come close to offering a true MR experience. The Microsoft HoloLens and the Magic Leap 2 are the two best high-end devices currently on the market.

Here is how we rate the technology....

IMMERSIVENESS & QUALITY — 4 OF 5

Immersive with only field of view limitation
True mixed reality makes it hard for users to tell what is real and what is not. The only notable limitation on the technology is the field of view that can break the immersion if the user stands too close to a digital object.

USABILITY & SCALABILITY — 3 OF 5

Easy to use but costly scalability
Mixed reality is relatively easy to use as it is typically a single worn headset with software controlled by simple hand gestures. There is, however, a small learning curve.

COST & TIME OF RUNNING A PILOT — LESS THAN $25K

Custom can be costly but there are ways to save
The most practical use cases of mixed reality can be achieved with off-the-shelf apps whcih makes it cost-effective on the software side. Sometimes custom 3D assets can be developed to be added to these existing apps. Additional limitations are in the cost and fragility of the device (based on a $5,000 per headset cost).

MIXED REALITY

Beyond custom building 3D assets, most practical applications of mixed reality can be implemented using off-the-shelf apps.

Dynamics 365 Remote Assist

Microsoft's Remote Assist allows users to share a real-time view with experts remotely to get the necessary help needed while staying hands-free. This app also enables experts to make spatial annotations similar to Vuforia Chalk mentioned previously under AR apps.

Dynamics 365 Guides

Microsoft Dynamics' 365 Guides is a mixed reality application for the Microsoft HoloLens 2 that helps operators learn during the flow of work by providing holographic instructions when and where they're needed. These instruction cards are visually tethered to the place where the work is to be done and can include images, videos, and 3D holographic models. Because operators see exactly what needs to be done, and where, they have the potential to get the job done faster, with fewer errors.

The Pros

The experience enables truly hands-free computing as the device is controlled primarily through hand gestures.

Users can do many of the same tasks in a mixed reality device that they could do on a smartphone or computer.

The Cons

Hardware is expensive at over $5000 per unit.

Limited to simple interactions.

Current hardware has a small field of view, which can take away from the immersiveness of the experience.

A Real Life Case Study

Using the Microsoft HoloLens, technicians working with Siemens' are able to view all the relevant information needed to prepare vehicles for operation anywhere. The service employee has full access to all necessary documents and information through the mixed reality interface. The interface guides technicians through service reports and prompts them on all necessary measurements needed for report implementation. Technicians use audio commentary to document and record results making them immediately available to all other departments.

If technicians run into issues while completing a report, mixed reality makes it possible to remotely collaborate with experts anywhere in the world. The photo below shows what a remote collaboration session with MR looks like. The technician wearing the headset can see the person they are calling in an interface that can hover directly above the work surface. The person on the other end can see exactly what the technician is seeing through the cameras on the front of the headset. During a call, the spatial annotations can be drawn in by the person on the other line further helping the technician quickly navigate the intricacies of their machinery.

Technicians at Siemens completed maintenance tasks much faster and more accurately, minimized human error, and immediately recorded service reports in the field using MR glasses.

THIS TECHNOLOGY IS WELL-SUITED TO:

Real-time remote support

No more flying a specialist in to solve complex problems or troubleshoot issues. With mixed reality devices, users have the ability to wear a device and bring the expert to them digitally from anywhere.

On the job training

If a user needs to train someone on the job for complex tasks or muti-step inspections, mixed reality can be used to create digital standard operating procedures that employees can use as guides while on the job.

THIS TECHNOLOGY IS NOT SUITABLE FOR:

Environment Based Training

Similar to AR, any scenario that would require a user to navigate a digital environment would be nearly impossible in mixed reality since it is intended to leverage the environment around the user. It is best used in object-centred experiences that don't need an environment.

This table provides considerations regarding which XR technologies might be best suited to particular areas of aerospace technical training today, based on the evolving nature of the technology.

	360 Video & Photo	Stand Alone VR	PC VR	Augmented Reality	Mixed Reality
SUMMARY OF RATINGS					
Immersiveness & Interactivity	2	3	4	3	4
Usability & Scalability	4	4	3	4	3
Cost of Running a Pilot	< $25,000	$100,000 +	$100,000 +	< $50,000	< $25,000
Lead Time for Pilot	~ 2 Months	4+ Months	4+ Months	~ 4 Months	~ 2 Months
POSSIBLE APPLICATIONS					
Safety Training	✔	✔	✔	✖	✔
Conducting Inspection	✖	✖	✖	✔	✔
Procedural	✔	✔	✔	✔	✔
Training others	✖	✔	✔	✖	✔
Diagnostic	✔	✔	✔	✔	✔
Repetitive tasks	✖	✔	✔	✖	✔
Group training	✖	✔	✔	✔	✔
New hire – work environment	✔	✖	✖	✔	✔
Foreign Object Debris (FOD)	✔	✖	✔	✖	✖
Aircraft familiarization	✔	✔	✔	✔	✔

What to consider when looking at XR Technologies

Extended reality is going to continue to rise as new products, innovations, investments and use cases emerge.

As the hardware evolves, costs will go down, more devices will become available and more creators will emerge to develop off-the-shelf tools or training scenarios that can be utilized by companies in all industries, including aerospace. One of the most likely forms XR will take in the future is that of a hybrid device, with which a user can seamlessly switch between all types of XR, making it more versatile and scalable. Devices will also heavily rely on other transformative technologies like AI and 5G to make them more effective.

XR won't replace educators. Instead, it will serve as a tool to help you further enhance what you do best, while allowing you to better connect with the next generation of learners.

Before diving headfirst into XR, it's important to consider a few things that will help avoid costly mistakes and ensure focus on what really matters.

1 UNDERSTAND THE AUDIENCE

There is a wide range of XR technologies and applications available for businesses to utilize. It is important to understand that some populations will be more receptive to using new technologies than others. XR can be incredibly beneficial for youth, people with disabilities or those who struggle to absorb knowledge through traditional teaching methods such as sitting in a classroom or reading training manuals. Understanding who the end user will be, and including them in the conversation early on, will help determine which technology will be the best fit.

2 DEFINE THE OBJECTIVES

It is vital to clearly understand the problems that need to be solved as well as what technology should be utilized to solve them. Like all tools in a tool belt, XR can be beneficial in some areas and less so in others. For example, XR is for things like safety training or remote support. Whereas teaching someone how to use basic hand tools or perform tasks that require fine motor skills might not be a good fit if it lacks tactile feedback.

3 BUILD A GOOD TEAM

Consider working with XR companies or industry experts to help you quickly navigate the landscape, focus on the most impactful areas first and avoid costly mistakes. Many companies will offer free consultation that could also help you quickly understand if XR is a viable solution based on your budget and needs.

4 BE FOCUSED AND STRATEGIC

Starting slow is critical to the success of new technology rollouts. These technologies and their capabilities will help you develop an in-depth understanding of it and get you thinking about where and how to use it. When it comes to selecting the physical hardware, it can get overwhelming. Reputable brands might be more expensive than the alternatives, but at the end of the day, usability and stability is key. Always start with one and test it thoroughly.

FINAL WORDS

Where to Start

Explorations have to start somewhere. Information from all data collection and lines of evidence indicate there are areas of aerospace technical training where XR technologies is likely sufficiently sophisticated and affordable enough now to create a quality learning experience. By doing these things first, time will pass and the XR industry will develop and grow. As a result, cost of creation of quality XR learning experiences may decrease. In addition, improvements in XR experiences (such as improved resistance and required precision in performing training tasks in XR) may happen. This will allow for the expansion of XR to more realistic simulations of more sophisticated and precise aerospace training tasks and activities.

Onboard New Hires

Participants, key informants and findings from the Evidence Synthesis suggest XR in aerospace technical training would likely be well suited for the onboarding of those who are new to the sector or to a particular role. As said concisely by one participant: "I don't believe that VR will be the means to train someone to become proficient in an activity. It can create awareness [of what is needed] but not proficiency." XR's capacity to expose trainees to tasks and competencies in a safe and lower stress environment that easily allows for repetition with material waste, may be an advantage for exploring its uses with new hires.

The Sector Demand Approach

In considering next steps for XR in aerospace technical training, industry demand could be considered. In aerospace, the majority of workers required are for the assembly function, and therefore consideration for the inclusion of XR in training might want to target the largest section of the workforce first. This can be broken down by structural and systems (fuel, electronic, hydraulic). Quality inspection and functional test make up approximately 12% to 15% of assembly of workforce and might be another priority area.

Where else might XR add value:

This research suggested that other areas where including XR might add value to aerospace technical training, includes safety, emergency response management, FOD training, inspection – training inspectors and getting others to understand inspection, Non-Destructive Testing, sealing, sheet mold composites, procedural and logistical processes, training others – getting the team to understand what others do and why, diagnostic – what's wrong and how to fix it - review the potential defects, repetitive tasks, upskilling on new processes (in-service training), and group training.

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