IMMERSIVE TECHNOLOGIES IN HEALTHCARE TRAINING & EDUCATION:

THREE PRINCIPLES FOR PROGRESS

Immersive Healthcare Collaboration

UNIVERSITY OF LEEDS

IMMERSIVE TECHNOLOGIES IN HEALTHCARE TRAINING & EDUCATION

SUMMARY

- The COVID-19 crisis has fundamentally transformed the healthcare training and education landscape, resulting in a desperate need for a system-wide exploration of scalable, flexible, user-friendly and resilient solutions that mitigate the long-term impact on the development of a skilled healthcare workforce that can deliver high-quality patient care.
- A new generation of "immersive technologies" – a collection of tools, sometimes grouped under the term eXtended Reality (XR), including enclosed 3D Virtual Reality (VR) environments through to digital projections that overlay the real-world to create "Augmented/Mixed Reality" (AR/MR) – have potential to address many of the challenges faced in healthcare training and education.
- Despite their potential, challenges exist in the design, development, implementation, and understanding of immersive training environments and must be overcome if these technologies are to realise their potential.
- System development and implementation must focus on learning outcomes (e.g. academic, social and emotional learning, reduction in drop-out rates, demonstration of non-inferiority and subsequently, superiority over traditional non-immersive training methodologies) and patient-care related processes (e.g. safer delivery, reduced morbidity and readmission rates).
- Bold policies based on sound scientific evidence need to be developed, both in the short – and long-term – that are practically applicable and acceptable to the variety of stakeholders – to ensure that the power of immersive tools is harnessed for efficient and effective health education and training delivery.

THIS REPORT HIGHLIGHTS 3 PRINCIPLES THROUGH WHICH PROGRESS IN THIS AREA CAN BE ACCELERATED. THESE PRINCIPLES ARE:

1. The design and development of immersive tools that are driven by learning requirements, and informed by the science of human behaviour and cognition.
2. Rigorous evaluation prior to, and during implementation of immersive technologies into the healthcare system through open science and transparent research practices.
3. Principles 1 and 2 are best achieved by fostering a culture of collaboration, inclusivity and solidarity between developers, educators, scientists, industry, policy makers and healthcare professionals to maximise uptake, accelerate learning and improve patient outcomes.

INTRODUCTION

The COVID-19 pandemic has seen the return of retired healthcare workers and the redeployment of thousands of staff and students to the frontline. The challenges of delivering training and education in healthcare have never been more pronounced. The enhanced requirements for infection prevention and control have highlighted the challenges of education and training approaches that rely so heavily on master-apprentice models, face-to-face delivery and patient access. Digital simulation is commonly used across a number of industries to make systems resilient to extreme surges in demand, crisis management and the need for rapid and continuous reconfiguration of services in response to dynamic risks[1]. The emergence of a new generation of digital simulation tools known as “immersive technologies” presents opportunities that could address many of the difficulties faced by educators and learners across the healthcare system today and in doing so fundamentally transform the future delivery of training and education.

Immersive technologies are a collection of tools ranging from enclosed 3D Virtual Reality (VR) environments through to digital projections that overlay the real-world to create “Augmented/Mixed Reality” (AR/MR) and are sometimes grouped under the term eXtended Reality (XR). They exploit human perceptual processes to immerse users[2] and produce a sensation of presence[3] through interacting with computer-generated three dimensional environments[4]. The design space of immersive technologies (and their potential for accelerating learning) is shaped by their unique ability to support naturalistic interactions with computer interfaces[5].

While digital simulators have been used in healthcare for over two decades (principally in surgical training[6]) with varying degrees of success (from the perspectives of adoption through to improved patient outcomes[7,8]), the substantial investments made from some of the world’s largest companies, along with technological advances in the power of low-cost computing devices and breakthroughs in artificial intelligence means we are on the precipice of a new technological revolution. For healthcare, the impact is likely to transcend specialty, with an extremely broad set of use-cases- from physical[9–15] through to psychological training[16–22]. The potential outcomes are also broad and varied- from acting as an adjunct to traditional face-to-face training to fully replacing current modes of delivery.

This revolution also brings challenges that must be overcome if these technologies are to realise their potential of improving academic, social and emotional learning[23], increasing cost-effectiveness (faster, and with reduced time invested by the ‘master’) and providing scalable delivery solutions[24]. Improper implementation and poorly designed (or omitted) evaluation could risk the future of the technology (with industry concerned about “poisoning the well”[25]). This would place a considerable burden on the healthcare system, and could ultimately impact on the quality of patient care. Furthermore, in the face of a prolonged period of economic recession, and uncertain investment into the healthcare system that is in pace with inflation, prudent investment is an ethical and fiscal obligation.

Given this context, there is a desperate need for a system-wide exploration of how the healthcare community can move forwards with scalable, inclusive and evidence-based solutions that can supplement, or in some cases replace, traditional methods. To this end, we have brought together a consortium comprising educators, scientists, healthcare practitioners, and engineers, who work with immersive technologies across all strata of healthcare delivery, to outline a set of principles that can nurture progress in a manner that ensures immersive tools become central to efficient and effective education and training delivery in a post-pandemic world.

PRINCIPLE 1:

DESIGN & DEVELOPMENT SHOULD BE DRIVEN BY LEARNING NEEDS

Numerous technological revolutions in education have been touted in the past, but they have not always led to improved learning outcomes. A seminal report from the Organization for Economic Cooperation and Development[26] found no correlation between investment in classroom technologies and academic achievement and stressed the need for a new approach to deliver technologies in education. These poor outcomes are not necessarily a failure of technology, but reflect a failure to adopt "backward design" approaches that consider the desired outcomes and formulate plans to achieve them[27].

To maximise the potential of immersive technologies and ensure they do not suffer the same fate as many preceding innovations, we must strive to answer a number of critical questions: (1) Which learning tool, including traditional and immersive methods, presents the optimal solution to achieve the specific learning outcome? (2) Which immersive technologies have been shown to improve outcomes in high-quality research (i.e., randomised controlled trials and quasi-experimental designs), for whom, and under what conditions? (3) How do we design and implement immersive technologies to achieve specific learning objectives? and; (4) Why and how do immersive technologies accelerate the learning of specific outcomes when compared to other tools? Or, in summary, "Immersive – so what?"

Considering the substantial resources associated with developing and implementing these technologies it is critical that we consider the pedagogical purpose. Simply digitising training can afford a number of general benefits, allowing for example, asynchronous learning (e.g. to trainees on placement or otherwise working/learning 'offsite'[28], higher volumes of practice with constant variation[29], the opportunity for distributed practice[30], the provision of feedback[31] and the use of predictive analytics to assert revision of skills training and allowing progression maintenance[32,33]). In tandem, we must consider the specific benefits of immersive when choosing to develop or implement a new tool into the curricula – or otherwise risk being a gimmick. Strong cases could be made for tasks where skilful interaction with the world is required[34] – from breaking down a complex skill into its component parts and allowing mental[35–37] and physical rehearsal[36,38–40], or where immersion and the sense of presence in the environment is pedagogically important (e.g. making decisions under stress[41]).

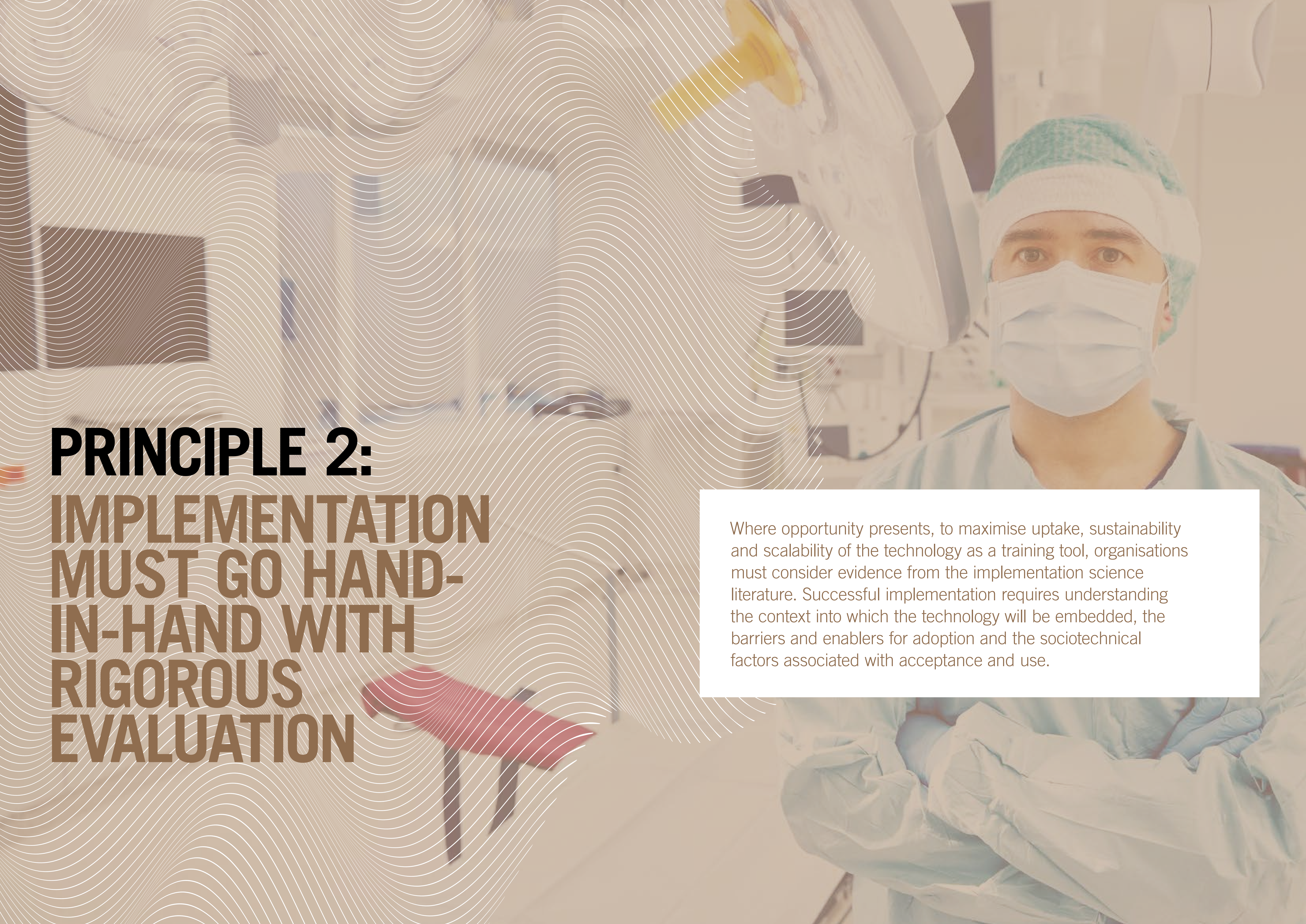
After deciding on the pedagogical purpose, we must consider the features necessary for the tool to address learning needs and improve outcomes. We propose that a deeper appreciation of the processes underlying human skill acquisition[42–44] and the appropriate implementation of what we already know about human factors, human perception, and human-machine interactions e.g.[45] can facilitate this process.

Much of the science and practice of training and education rests on our understanding of the cognitive processes involved in learning and performing a given task (see for example the influence of cognitive load[46,47] and the application of fundamental research on visual search strategies[48–50]). Cognitive science provides a framework that can help us understand the complex interactions between cognition, perception and motor control that occur when people work in immersive environments. At the time of writing, major advances are being made in the inclusion of haptic feedback, eye-tracking, and integration of wearable sensors capturing physiological parameters such as heart rate and electrical brain activity[51], in low-cost commercially available devices.

COGNITIVE SCIENCE PROVIDES A FRAMEWORK THAT CAN HELP US UNDERSTAND THE COMPLEX INTERACTIONS BETWEEN COGNITION, PERCEPTION AND MOTOR CONTROL THAT OCCUR WHEN PEOPLE WORK IN IMMERSIVE ENVIRONMENTS

Without the commensurate understanding of what these measures tell us about cognition and how that relates to learning and performance on a specific task, these additional "data sources" may be superfluous, or serve as distractions.

To illustrate, consider the case of including haptic information in a system e.g. force feedback to simulate the sense of touch. It seems intuitively obvious that such information could be useful in a variety of circumstances – from surgical procedures[52] through to pathology (e.g. post-mortems, macroscopic examination and grossing) and this is a motivating factor for many companies wanting to embed haptics into their system. But how might they best implement, and ultimately assess whether the inclusion of haptic information was appropriate and useful for the end-user? Answers to these critical questions are hampered by our limited understanding of haptics across different learning contexts (e.g. it is unclear if visual and haptic information might be weighted differently across the training process for say, a lumbar puncture, intravenous administration for medicines or minimally invasive procedures more generally). For a developer, the risks of including such information (and thus causing a mismatch between haptic and visual information that drives behaviours that deviate from the real-world task) could be worse than no haptics at all. We need to tread carefully and advance our theoretical understanding of the sensory processes underlying learning in parallel with technology development and implementation.



PRINCIPLE 2:

IMPLEMENTATION MUST GO HAND-IN-HAND WITH RIGOROUS EVALUATION

Where opportunity presents, to maximise uptake, sustainability and scalability of the technology as a training tool, organisations must consider evidence from the implementation science literature. Successful implementation requires understanding the context into which the technology will be embedded, the barriers and enablers for adoption and the sociotechnical factors associated with acceptance and use.

Most of today's immersive systems have a degree of face validity (i.e. they present relatively realistic simulations of the real-world task) and this may be a key component for immersion and driving a sense of presence, but it does not necessarily translate to learning. Some systems may show construct validity, confirming a simulator can discriminate between users with different levels of real-world clinical skill[56–61]. While this is a critical step in the development of an effective tool[13,62–67], it is often tested only after being implemented in curricula and operationalised crudely (e.g. comparing experts against novices). There is also a concern about the nature of skill development in virtual environments. When passive control strategies are employed users may be able to follow instructions successfully but fail to develop the internal models necessary to perform the task without guidance[68,69].

Most critical to demonstrating that an immersive tool can be useful in the training and education process is showing transfer learning (i.e. how learning in simulation carries over to the real-world task) and relatedly, predictive validity (i.e. system performance can predict real world performance at a future time point). Although there has been little reported research exploring this important question, a recent study suggests that student performance in a VR dental simulation better predicts later clinical performance than traditional assessment[9]. More comparative work with existing tools and approaches, with a focus on real world performance and outcomes is needed.

Reflecting on Principle 1, we must also consider the appropriateness of the chosen outcome measure to the learning need and how we are navigating towards this outcome. This may be assessed quantitatively or qualitatively and may consider technical and non-technical skills, social and emotional learning, reduction in drop-out rates, demonstration of non-inferiority and subsequently, superiority over traditional non-immersive training methodologies. On longer time-scales, evaluation should assess impact on patient level outcomes (e.g. safer delivery, reduced morbidity and readmission rates). Weighing the importance of different outcome measures will be dependent on the stakeholders and the specific use-cases of each tool.

> **AN ORGANISATION CONCERNED ABOUT A POTENTIAL SKILLS GAP FOR STAFF IN ENGAGING WITH A NEW TECHNOLOGY MAY USE THIS FRAMEWORK TO UNDERSTAND BARRIERS AND IMPLEMENT PROCESSES THAT INCREASE THE READINESS AND PREPAREDNESS OF ITS WORKFORCE TO OPTIMISE THE IMPLEMENTATION PROCESS AND MAXIMISE THE DESIRED OUTCOMES.**

In the majority of cases, we accept that the acquisition of new technology is not driven by validity or outcomes, but dictated by finances. In making such decisions, contracting the services of health economists with expertise in modelling training and technology interventions costs is highly encouraged. Where opportunity presents, to maximise uptake, sustainability and scalability of the technology as a training tool, organisations must consider evidence from the implementation science literature. Successful implementation requires understanding the context into which the technology will be embedded, the barriers and enablers for adoption and the sociotechnical factors associated with acceptance and use[70]. The Adapted Implementation Model for Simulation (AIM-SIM)[71] provides a systematic framework designed to increase implementation capacity in simulation-based medical education. The model includes three implementation phases: (i) stakeholder engagement and context exploration, (ii) pre-implementation planning, and (iii) implementation with ongoing monitoring and evaluation. An organisation concerned about a potential skills gap for staff in engaging with a new technology may use this framework to understand barriers and implement processes that increase the readiness and preparedness of its workforce to optimise the implementation process and maximise the desired outcomes.

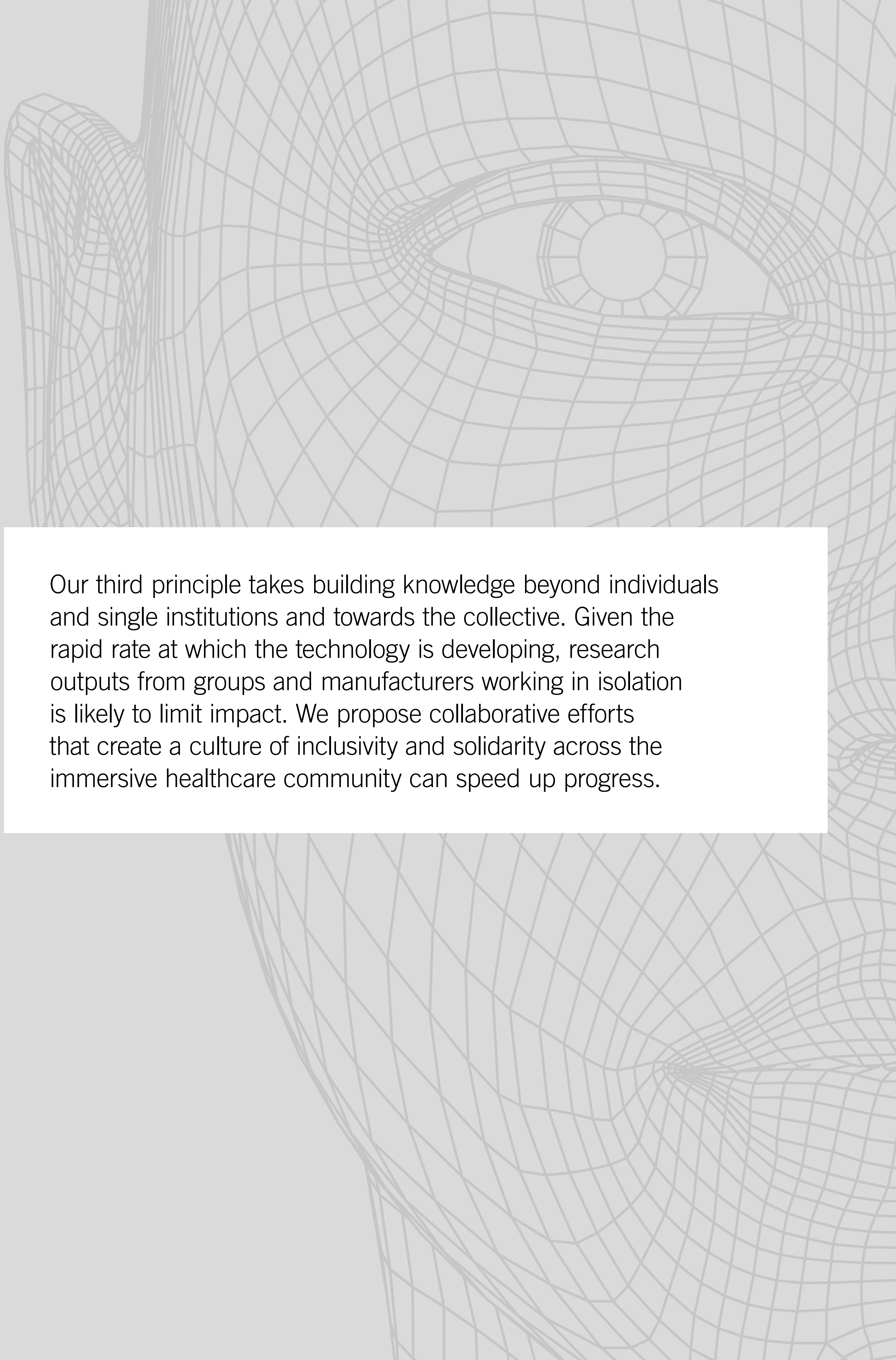
When these systems arrive in an organisation, much of the push for evaluation is "bottom up" and comes from individuals passionate about doing their best for trainees. However, because many studies take place only because of a local opportunity and are rarely well resourced, there is a bias towards conducting small-scale, statistically underpowered experiments with a single cohort, made up of a sample of convenience. To improve the quality of the work conducted at this level, we propose some practical steps.

A key driver in improving evidence-based medicine was the adoption of clinical trials registers[72]. The publication of study protocols providing a detailed account of the hypothesis, rationale and methodology of the study prior to undertaking research is now increasingly common across science, but rare in health education and technology related research. Recently, in the social sciences we have seen a move towards "Open Science" and rigorous research practices (e.g. replications, experimental designs with higher statistical power, sharing of analysis code). Learning from these examples and taking a lead on adopting cutting-edge, transparent research practices as the default standard would improve the quality of research in the literature and lead to longer term benefits of developing a firm grounding that underpins impact.

But how might we promote and encourage such behaviours? The Open Science movement has recognised that to incentivise stakeholders there needs to be a coordinated effort from journals, funders and institutions[73]. From a journal perspective, the adoption of the Transparency and Openness Promotion guidelines[74] and publication of pre-registered analysis plans would incentivise individuals to submit their research and analysis plans in advance of conducting data collection and reduce the risks of cherry-picking favourable outcomes post-hoc; a practice that makes reproducibility a challenge and inflates the rate of false positives in the literature. To facilitate collaboration in traditional clinical research, there are often financial rewards for supporting recruitment into multi-site clinical trials that help in meeting the costs of additional staff, facilities, equipment and support services (e.g. the NIHR Clinical Research Network in the UK). An equivalent network supporting training and education research could, for example, allow clinical educators to provide local support for wider initiatives through recruitment of learners.

PRINCIPLE 3:

A CULTURE OF COLLABORATION SHOULD BE FOSTERED TO ENSURE EFFICIENT & EFFECTIVE USE OF IMMERSIVE TECHNOLOGY



Our third principle takes building knowledge beyond individuals and single institutions and towards the collective. Given the rapid rate at which the technology is developing, research outputs from groups and manufacturers working in isolation is likely to limit impact. We propose collaborative efforts that create a culture of inclusivity and solidarity across the immersive healthcare community can speed up progress.

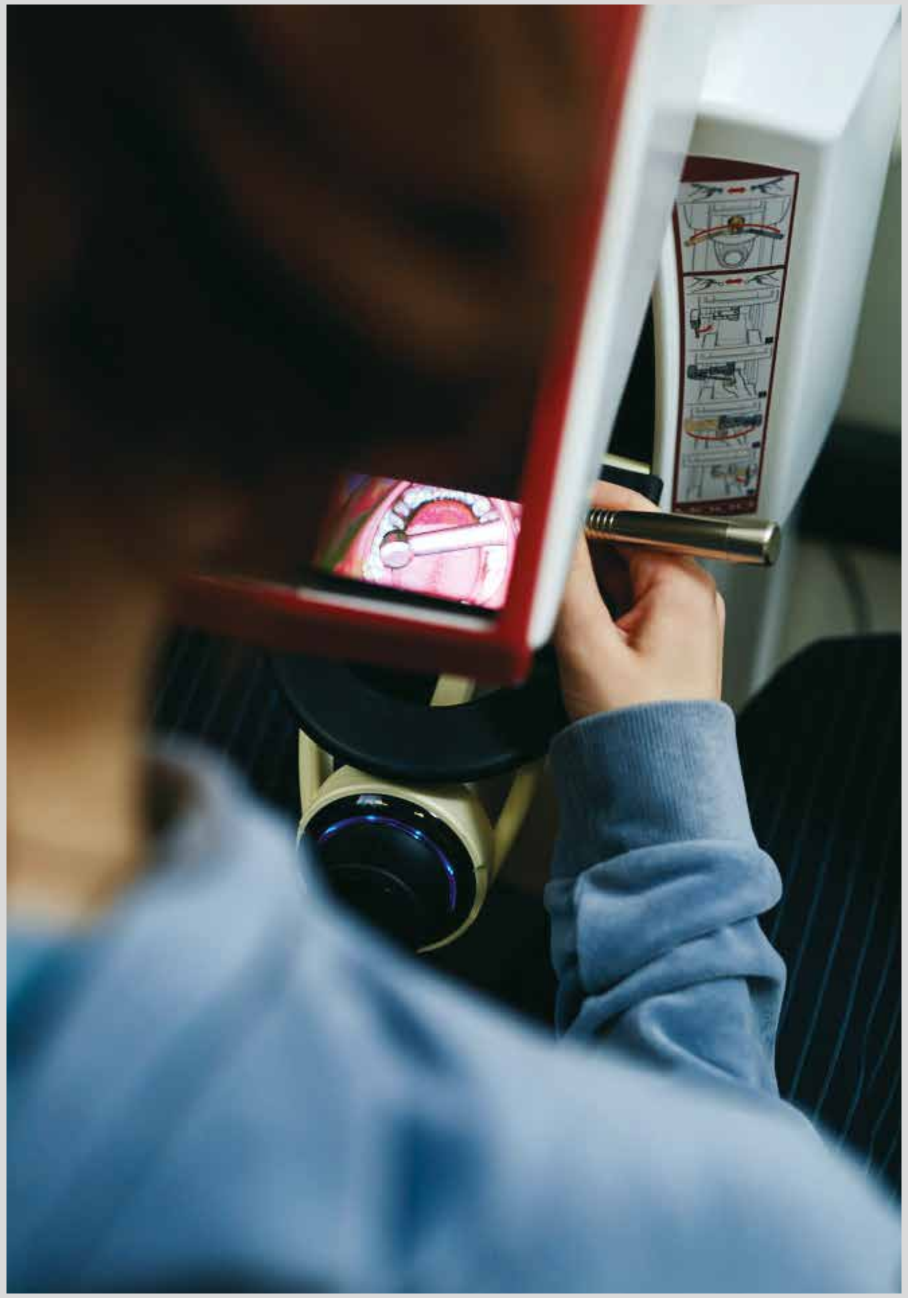
The value of collaboration through multi-site randomised controlled trials (RCTs) to health sciences is well-established, but it is also the case that such studies come with considerable logistical challenges and resource requirements. Given the inherent digital nature of immersive technologies, many issues can be mitigated: Immersive technologies lend themselves well to delivering multicentre, cloud-based, integrated trials where precise data acquisition can be captured, randomisation can be delivered, and anonymized evaluation undertaken. There is clearly much to gain (based on the issues highlighted in Principle 2) through multi-site RCTs, including increasing the statistical power, generalisability of findings, and testing the feasibility of wide-scale rollout.

> **THE INCREASED ADOPTION OF REMOTE WORKING PRACTICES IN A POST-PANDEMIC WORLD IS LIKELY TO ACCELERATE THE DEVELOPMENT OF THE INFRASTRUCTURE, KNOWLEDGE AND BANDWIDTH OVER THE COMING YEARS THAT ALLOW ROUTINE SHARING OF ANONYMISED LARGE-SCALE DATA**

The digitalisation of these technologies also presents a unique opportunity for harvesting "big data" in ways that could boost collaboration and efficiency. Through the use of big data we can also visualise and make available information in different ways to a broader audience like never before. For example, immersive technologies make it possible for us to collect detailed interactions in immersive environments in an automated fashion – from individuals through to team interactions. Uploading datasets from different parts of the globe, including low – and middle-income countries, with appropriate consent and in accordance with General Data Protection Regulation (GDPR) and local regulations, to a structured, machine-readable database that links through to a central anonymised training record could allow large-scale science to take place rapidly. A recent example of such working comes from the COVID-19 Open Research Dataset[75] – where scientific papers on the coronavirus are collated and structured to facilitate text-mining. In the immersive sector, analogous data sharing and assimilation could yield rich information on the variables that predict learning transfer and extrapolate tacit factors of expertise that may thus far been explicated through qualitative methodologies (e.g. interprofessional collaboration and non-technical skills).

The increased adoption of remote working practices in a post-pandemic world is likely to accelerate the development of the infrastructure, knowledge and bandwidth over the coming years that allow routine sharing of anonymised large-scale data. Beyond regulations, there are practical issues, such as the ownership of data and intellectual property that need to be overcome. If the field increases its adoption of the open science practices described in Principle 2 and there is a widespread expectation of transparency in experimenter design and analysis (e.g. journal guidelines), the competitive advantage for companies will shift away from data ownership. If this culture is supported by a quality assurance system administered by an appropriate body (which for example rates the quality of evidence and openness and transparency of the research that underpins a system) that would increase industry motivation to share data and in doing so, more closely align the goals of academia, industry and healthcare education.

With large-scale data collection readily amenable and wide-spread roll-out possible, wider issues around diversity and inclusivity come to the fore. Biases in the technology development process (e.g. discriminatory algorithms[11,76]) are well-documented and there are specific concerns about system inclusivity for people with disabilities (e.g. visual[10,77], motor[78] and auditory difficulties[79]). An indication that there is much work to be done here comes from the observation that visual fitness of participants in immersive research is rarely reported. This may be because most studies do not take any measures of vision and/or there is selection bias – participants who like to use and can comfortably wear XR technology volunteer for experiments. If immersive tools are to become mandatory for training and education, co-design with industry will be necessary to develop accessible solutions.



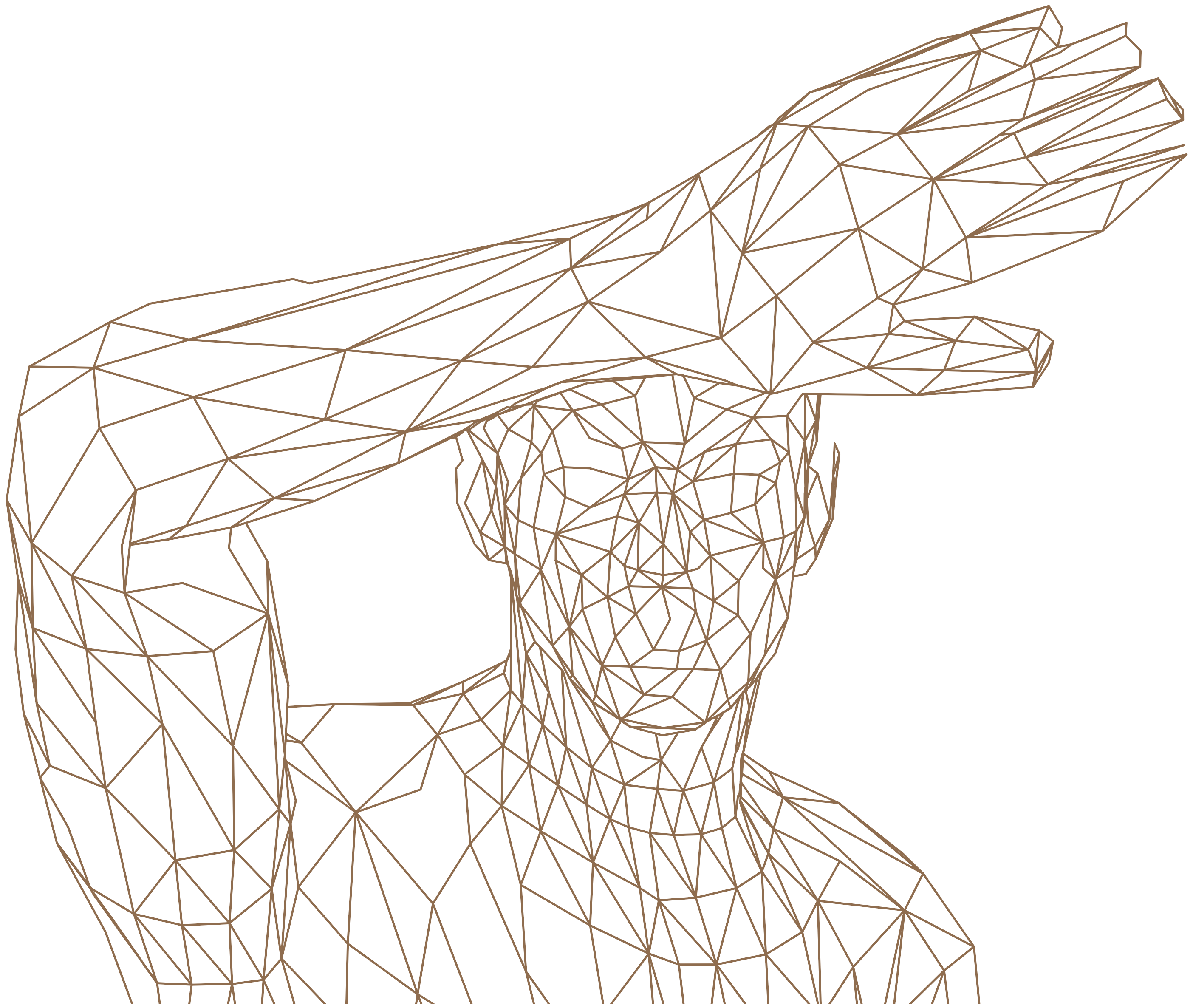
LOOKING FORWARD

Appropriate priority must be given to healthcare training and education research when considering the factors that impact on patient outcomes and the management of the health service. The pandemic has reinforced the importance of healthcare training and education and the emergence of novel, exciting technologies has increased attention on the possibilities. Through developing these three principles, it has become clear to this consortium that we need a combination of bottom-up drive (from clinicians, educators, researchers, developers) complemented by top-down initiatives (organisations, funders, journals) that facilitate work across disciplines, institutions, fields, sectors and countries to build capacity and change perspectives through the use of immersive technologies.

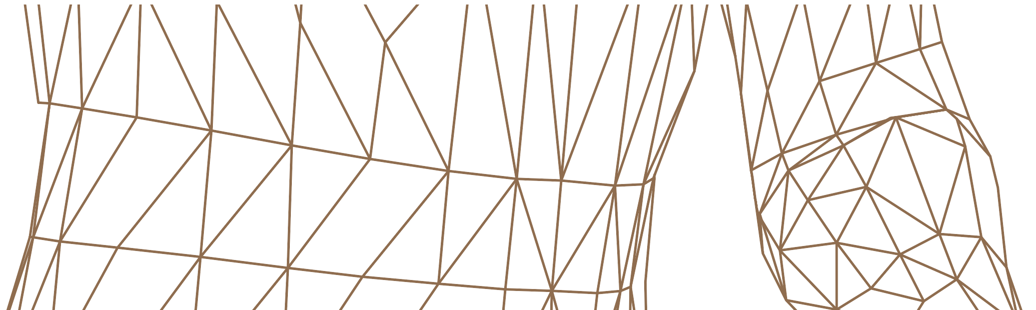
These efforts need to be underpinned by a research framework that can support effective knowledge exchange. The creation of interdisciplinary endowed professorships coupled with changes in legislation and organisational processes that reward collective high-quality science, training and education delivery and support industry collaboration would be important steps in the right direction. We must also come to a consensus on what outcomes research initiatives should be leading to, in the short and long term – from academic impact and social and emotional wellbeing of individuals through to health and quality of life outcomes across the system. Achieving these ambitions will only be possible with appropriate resources.

We cannot underestimate the challenges ahead and it is with the future in mind that we have brought together this Immersive Healthcare Consortium, with representation from healthcare, academia and industry. Our hope is that this report can ignite a cultural shift towards collaboration across the immersive technology community, with inclusive tools that have pedagogical purpose at the forefront of the development process and create an evidence-base founded on robust, open and transparent scientific research that informs implementation.

Due to the lessons learned during the pandemic, the healthcare system is poised for a training and education delivery reform. By following the principles outlined herein, we are optimistic that the potential of these technologies can be harnessed for the benefit of the healthcare community and patient care.



OUR HOPE IS THAT THIS REPORT CAN IGNITE A CULTURAL SHIFT TOWARDS COLLABORATION ACROSS THE IMMERSIVE TECHNOLOGY COMMUNITY, WITH INCLUSIVE TOOLS THAT HAVE PEDAGOGICAL PURPOSE AT THE FOREFRONT OF THE DEVELOPMENT PROCESS AND CREATE AN EVIDENCE-BASE FOUNDED ON ROBUST, OPEN AND TRANSPARENT SCIENTIFIC RESEARCH THAT INFORMS IMPLEMENTATION.



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