XR for Social Impact: A Landscape Review

GAMES FOR CHANGE

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About XR for Change

The XR for Change initiative seeks to encourage dialogue, collaboration, advance equity and inclusion, and inspire creative use of emerging technologies for social impact. XR4C hosts various convenings throughout the year including XR Talk and Play panel discussions, and the XR Brain Jam, a 2-day long event pairing developers and researchers in order to create new XR prototypes for potential research applications. The initiative's work throughout the year culminates at the XR for Change Summit during the annual Games for Change Festival.

About Games For Change

Since 2004, Games For Change (G4C) has been empowering game creators and innovators to drive real-world change, using games and immersive media that help people to learn, improve their communities, and contribute to make the world a better place. G4C partners with technology and gaming companies as well as nonprofits, foundations and government agencies, to run world class events, public arcades, design challenges and youth programs. G4C supports a global community of game developers working to use games to tackle real-world challenges, from humanitarian conflicts to climate change and education.

Foreword

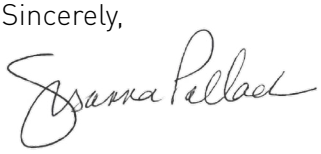
DEAR READER,
Our mission at Games for Change is to empower creators and social innovators to use games and immersive media to drive real-world change. Over the past 17 years, we have enjoyed working with people from a variety of sectors who share our belief that games and immersive media have power beyond entertainment. It is a global community, embracing educators and researchers, policymakers and health-care professionals, game developers and nonprofit leaders, and many more.

When we launched the XR for Change initiative three years ago, we set out to demonstrate how XR can contribute to social impact work. Over that time, we have seen great strides in the use of XR, and the emergence of a body of work addressing many critical issues. With this white paper, we have chosen to focus on several key areas—healthcare, education, and workplace training—where we are witnessing heightened innovation and investment. This movement is being driven by inspired creators, university researchers, scientists, entrepreneurs, impact investors and others, with a shared understanding that the emerging XR industries can reflect the virtues of the "double-bottom" line, spurring innovation, generating revenue, all while achieving social good.

Through the examples offered in this white paper, we aim to highlight the many areas of opportunity in these three fields, and to encourage further innovation and investment in XR for social impact. Technology doesn't achieve positive social change automatically—collectively, we have a responsibility to ensure that it equitably serves all of society. In this way, XR presents both a remarkable opportunity and a challenge.

We hope this paper inspires you to accept that challenge.

Sincerely,



Susanna Pollack
President, Games for Change

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Abstract

SPURRED BY growth and investment, immersive technologies like virtual and augmented reality have brought about a much-needed change across several industries. These technologies are collectively referred to as "extended reality", or XR. However, due to the scale, scope, and complexity of these technological changes, it can be difficult to survey its application for social good. This report aims to untangle the wide net of applications cast by impact-driven XR for various stakeholders interested in engaging with this technology. By including both industry-leading use cases and novel/experimental approaches, this report provides a landscape review for policymakers, entrepreneurs, investors, academics, working professionals, and civil society members to understand exactly how XR technologies are (and will be) applied for social impact in healthcare, education, and workplace training. Since these industries have a clear correlation to the quality of a nation's citizenry, the potential for positive social impact through technological disruption cannot be overstated. We project that the role of XR is bound to grow exponentially in these industries in the years to come, and this report also aims to encourage innovators and technology leaders to consider the social implications of that development.

Introduction

ONE OF THE MAIN challenges of researching immersive XR technologies is the sheer volume of work that has been created over the course of the last few years. With research and development continuing amidst increased investment, new use cases are arriving with the potential to change how we live, learn, work, and interact with one another. These applications are tackling so many different issues that it can be difficult to find relevant information scattered amongst various resources. By combining an exhaustive literature review with valuable insights from several industry experts, this report helps amplify the voices of creators who are committed to developing impactful experiences in XR. This report should also serve as a primer for various stakeholders (such as policymakers, entrepreneurs, investors, academics, working professionals, or civil society members) that outlines how exactly this technology can be applied for social good, as exemplified through current and anticipated case studies. XR carries profound implications on our lives, and this report encourages its readers to consider how they might use these technologies in their own work to benefit society and culture at large.

Before continuing, it is important to define some of the terms that will appear throughout this white paper. 'XR' stands for "extended reality" and is an umbrella term used to describe the varied immersive technologies that integrate the physical world with the virtual world. These include:

Virtual Reality (VR): Experiences that fully immerse users inside a digitally constructed environment, completely obscuring their view of the real world. VR experiences can be accessed using a VR headset or a head mounted display (HMD), such as the popular Oculus Rift, HTC Vive, Valve Index, or Google Cardboard.

Augmented Reality (AR): Experiences that overlay digital content over the real environment such that users retain their ability to view the real world along with the virtual additions. However, the digital content is usually unable to interact with the real world. AR experiences can be accessed using a smartphone, tablet or AR glasses.

Mixed Reality (MR): Similar to AR experiences, with the added capability of digital content being able to interact with objects of the real world in real-time. It can be accessed using a dedicated MR headset such as the Microsoft HoloLens.

Introduction (CONTINUED)

XR technologies should no longer be considered emergent or experimental. According the Gartner Hype Cycle (a definitive guide to trends in new technologies)[1] XR graduated from emerging technology status in 2019, and has seen tremendous growth subsequently. According to IDC, the worldwide spending on XR will reach $18.8 billion in 2020,[2] while Visual Capitalist expect its market size to increase to more than $209 billion by 2022,[3] and $571.42 billion by 2025 according to Bloomberg reports.[4] This growth has led to many new XR inventions across different industries.

Growth and innovation, however, do not necessarily lead to positive social impact. One definition of a "positive technology" is when a technology is consciously designed to foster wellbeing, strength and resilience in individuals or groups.[5]

Jessica Lindl (GM and VP of Social Impact at Unity Technologies) describes the ways that XR can be seen as a positive technology that promotes social change:

> XR has the greatest potential for deep engagement, deep empathy, and therefore better outcomes...XR touches on almost every issue of the modern world from civic justice to racial equity to police brutality. If there's a cause, there's an XR experience that can unlock your imagination and break open your heart in [new] ways."

Although use of XR can be seen across many non-entertainment industries, this report focuses on three industries in particular: healthcare, education and workplace training. XR is likely to grow exponentially in these industries which closely correlate to quality of life and carry the greatest potential for positive social impact through technological disruption. As XR becomes more affordable and user-friendly, it is steadily being adopted by hospitals and healthcare facilities to improve accessibility, affordability, and effectiveness of medical interventions. XR is also recognized as a tool in classrooms to make learning more accessible, engaging, and personalized. Workplaces and manufacturing environments also view XR as a technology to facilitate the transfer of knowledge, improve productivity and safety. A body of research also shows XR's effectiveness in stimulating empathy that encourages individuals towards prosocial behavior.

XR for Healthcare

HEALTHCARE SPENDING accounts for nearly 18% of the United States GDP.[6] The need for effective, equitable, and affordable healthcare is evident, and technological innovations have played an important role in healthcare: from better diagnosis to efficient treatment of illnesses, positive technological developments have supported the medical needs of doctors and patients alike. XR is emerging as an example of a positive technology that is being increasingly embraced by the healthcare industry.

A 2019 report suggests that the global AR and VR markets in the healthcare industry are expected to reach $10.82 billion by 2025.[7] This projection was made prior to the global COVID-19 pandemic, which has dramatically accelerated use of telehealth and virtual services. Since then, consumer spending in telehealth has increased by 46%[8] or $250 billion.[9] This has pushed XR-enabled telehealth to the forefront of the healthcare industry. An example is Israel's Sheba Medical Center which plans to become the first fully VR-based hospital.[10] From cognitive therapy to physical therapy to pain relief, XR is quickly transforming the healthcare industry, changing the way doctors provide care to patients.

1.
Access to Healthcare

Access to affordable and quality healthcare services is key to ensuring public health equity. However, ethnic minorities in the United States do not have equal access to quality healthcare. Research shows that lower income individuals who are uninsured are more likely to delay seeking care, skip tests, or leave prescriptions unfilled, due to cost.[11] Location, such remote or rural areas, and physical limitations or lack of mobility that limit travel also impact access to healthcare. Hospitals or clinics that serve poorer communities may lack certain medical services or specialized personnel. And demand for healthcare often exceeds supply. The Association of American Medical Colleges states that the U.S. could face a shortfall of between 21,000 and 55,000 primary care doctors by 2023. Together, these can add up to significant delays in receiving appropriate care, and undue financial burdens on underserved populations.[12]

Telemedicine—healthcare services delivered through the use of the internet or smart devices—can shorten the distance between healthcare providers and patients and streamline healthcare delivery. A recent white paper by Accenture found that "82% of health executives agree that extended reality is removing the hurdle of distance in access to people, information and experiences" in healthcare.[13]

The potential of providing medical services remotely is opening new doors. AppliedVR (a pioneer of therapeutic virtual reality) and S.O.L.V.E. Health Tech (a health equity accelerator at UC San Francisco) have partnered on a study to determine how XR-enabled therapy can improve healthcare access and lower costs for underserved populations by bringing XR health technology into the home for remote patient care. [14]

By leveraging the immersive potential of XR, these applications enhance the feeling of physical presence during interactions and enable a more intuitive way of interacting with information. When coupled with biosensing technology, XR can enable doctors to remotely diagnose patients and explain their condition with life-sized 3D images. For example, students at Delft University of Technology are leveraging social VR platforms for designing a social VR clinic that facilitates virtual consultations for knee treatment, supporting patients with such physical limitations by eliminating their need to travel for consultations.[15]

XRHealth, a company that offers virtual reality treatments, recently launched a line of VR Clinics that brings personalized VR therapy into the homes of patients under the guidance of 'VR telehealth clinicians'.[16] Using this service, patients no longer have to commute to hospitals and wait in long queues to receive appropriate care or seek certain physical and cognitive rehabilitation services.

XR telehealth services can also provide a solution to the problem of unavailability of medical experts, particularly surgeons in remote areas. For instance, it allows a specialist situated remotely to extend their expertise to a local surgeon. Using augmented reality, Proximie allows remote experts to see the first-person view of the procedure being performed enabling them to collaborate with the local surgeon in real-time.

2.
Pain Management

One of the most promising uses for XR is in the field of distraction therapy and pain management. Distraction therapy reduces a patient's attention to the stimulus causing pain or apprehension (also known as the gate theory of attention).[17] Since pain is also psychological, the immersive nature of XR can distract patients from fixating on pain. XR can offer a non-invasive, drug free, non-addictive alternative to traditional pain management. For this reason, XR is used in hospitals as a non-pharmacological alternative to mitigate acute and chronic pain in patients. In 2015, a report by the journal *Psychology of Consciousness* reported an 82% reduction in pain levels in patients who received VR therapy compared to those who did not.[18] New research from Cedars-Sinai Medical Center showed a 25% reduction in pain scores in patients who were given VR therapy.[19]

XR has also been used as distraction therapy for burn victims. *SnowWorld* is an application developed by HITLab psychologist Hunter Hoffman that diverts a patient's attention away from pain by immersing them in a virtual snowy canyon where they could fly and throw snowballs at snowmen and penguins. After

several trials on U.S. Army veterans over the course of a decade, results showed patients reporting up to 50% less pain while playing *SnowWorld*.[20]

XR is also being used in hospitals to help ease side effects from chemotherapy. In addition to pain, nausea and vomiting, chemotherapy can also induce stress and anxiety in patients. VR therapy helps relax patients, and alter their sense of time, making treatments seem shorter. More than 82% of patients expressed an interest in using VR during subsequent chemotherapy treatments.[21]

A number of oncology clinics are using XR to help patients escape the confines of hospital rooms and take a virtual hike in nature, swim with dolphins underwater, or virtually interact with family members or other patients. This has been observed to ease pain and distress in patients and improve the patient experience.[22] Christiana Care Health System in Delaware and Penn Medicine in Philadelphia are few of the several hospital systems that have embraced VR to alleviate physical and psychological stress that often accompanies chemotherapy.

The use of XR has been shown to significantly reduce a patient's perception of pain during painful medical procedures decreasing the need for anesthesia. At the Orange Regional Medical Center in New York, VR therapy is being used to treat pain and anxiety in women during childbirth, eliminating the need for epidurals. Several pediatricians have also turned to XR to alleviate the pain and fear in children during routine immunizations, IV insertions, or blood samples. It is possible to reduce the pain in children by 59% and stress by over 70% while taking blood samples using this method.[23] The Starlight Children's Foundation is using VR therapy to distract children from painful procedures such as a lumbar puncture, where a needle is used to withdraw spinal fluid or administer medication.[24]

AppliedVR is a Los Angeles-based virtual reality platform aimed at alleviating pain. It was recently granted a breakthrough therapy designation by the Food and Drug Administration(FDA). This designation is granted to medical devices that are intended to treat life altering and debilitating health conditions that lack alternatives in the marketplace. Via an eight week program rooted in cognitive behavioral approaches, AppliedVR seeks to teach users fundamental skills that can provide pain relief, even without the use of a VR headset.

FIGURE 1 AppliedVR lets users take a virtual swim with dolphins, diverting attention away from pain. *(Source: AppliedVR)*

AppliedVR pain relief programs consist of an array of tools such as immersive education, dynamic breathing exercises, mindfulness exercises, and virtual trips that are woven into a curriculum developed with clinical psychologists. A study conducted by the company in July 2020 reported a significant decrease in chronic pain in patients who self-administered VR therapy at home.[25] Their programs have been deployed in over 200 hospitals including Cedar Sinai, New York Presbyterian and Cornell. Josh Sackman, president and cofounder of AppliedVR, remarks that

> "Our hope is that doctors build enough familiarity and confidence with VR therapeutics that it becomes one of the first things that they offer to patients. We also want to build enough evidence to make it possible for insurance companies to cover the cost of VR therapeutics, just like they do for medications and other types of medical devices."

The use of VR as a calming distraction has created a better patient experience by reducing the recovery time spent in hospitals, reducing the need for habit forming medications, and concurrently reducing the cost of care, making pain management a promising area ripe for the applications of XR.

FIGURE 2 Braveminds's virtual reality exposure therapy being used to treat PTSD in war veterans.
(Source: USC Institute for Creative Technologies)

3.
Psychological Therapy

Many Americans are affected by mental health disorders: 25% of the young adults, and 22% of the adult populations are said to be affected by a mental illness[26] and spend close to $225 billion a year on treatment.[27] XR's potential as an effective psychotherapeutic tool is being recognized in psychiatric and clinical psychology communities as an aid in mitigating this crisis.

Dr. Walter J. Greenleaf, a prominent neuroscientist and digital health expert at the Stanford University Virtual Human Interaction Lab explains that

> "The powerful thing about XR is that it's evocative, it can evoke a desired cognitive state or a mood state. This can be used to address PTSD, phobias, anxiety disorders, body dysmorphia or substance abuse addictions...It can also be used to magnify someone's facial expressions and nonverbal communication like body language and use it to teach people who are on the autism spectrum how to recognize nonverbal communication and facial expressions."

Patients who suffer from phobias, anxiety disorders, or PTSD can be immersed in virtual environments where clinicians can safely get them habituated by disconnecting the negative response associated with a place, object or event. For example, Bravemind is a VR exposure therapy tool to treat PTSD in war veterans, created by the Institute for Creative Technologies at the University of Southern California in collaboration with the US government. According to creator Dr. Skip Rizzo, "It's an approach that helps the patient to confront and reprocess difficult emotional memories, but in a safe place...Over time, there is a chance that the stimuli loses its potency to evoke an anxiety or fear response."

The clinical efficacy of such virtual reality exposure therapies, known as VRET is well supported by research[28] and is also being used to treat phobias such as claustrophobia (fear of closed spaces), fear of driving, acrophobia (fear of heights), fear of flying, arachnophobia (fear of spiders), and even social anxiety. This approach also eliminates the need for patients to rely on visualization (imaginal exposure therapy) or role-playing skills (in-vivo exposure therapy) to address their fears. Results of one large randomized control trial indicated that 77% [of people studied] picked VR treatment over imaginal or in-vivo exposure therapy. Recently, Rizzo and his team have also been working on VR therapy to treat PTSD related to sexual trauma and PTSD faced by healthcare workers battling COVID-19.

Similarly, VR can also be used to help manage reactions towards addictions and teach refusal skills to unlearn harmful behaviors. *Invite Only VR* is a vaping prevention game for teens, where players must navigate different

types of peer pressure, including the pressure to vape in various social settings and situations, applying their new knowledge in conversations with others, and effectively refusing their peers. *Invite Only VR* also uses voice recognition software, allowing for real-time practice refusing peers. Renew Recovery, a treatment center in Louisville, KY, is using VR therapy developed by BehaVR to help their clients seeking help for alcohol and drug addiction.[29] BehaVR is a virtual reality therapeutics platform for wellness and behavioral health.

Virtual Reality has also been able to successfully treat several eating disorders and anxieties related to body image issues. Psious, a VR company based in Barcelona, offers several VR simulations that help therapists reduce behaviors associated with mental illnesses in patients, including eating disorders. In one such simulation, patients find themselves in a dressing room. Facing a mirror, the patient sees a reflection of a virtual avatar. The patient is handed a controller, using which they can alter the body appearance of the avatar in accordance with their self-perceived body image. The therapist then inserts a virtual image based on the patient's actual body measurement. "This helps highlight the discrepancy between the patient's perception of their own body, and their actual dimensions."[30]

Most VR therapies are rooted in the same principles of Cognitive Behavioral Therapy (CBT) or Acceptance and Commitment Therapy (ACT), which are quite effective in facilitating behavioral changes when performed in the presence of a trained clinician. Researchers are now combining VR with various biosensing instruments such as EEG, heart rate monitor, skin conductance and temperature sensor, etc. to study the impact of VR therapy on the patient's brain and physiology. This helps create a feedback loop by obtaining real-time objective psychological assessment to the treatment that the patient is immersed in.

Adam Gazzaley, Professor of Neurology, Psychiatry and Physiology at UCSF and the founder of Neuroscape, elaborates the importance of a closed loop system:

> "A closed loop is where the environment that an individual experiences is being adapted in real-time, based upon their own state, and that state could be assessed based on physiological and neural data. This gives us a much more comprehensive view of the stress, the arousal, the attention, and the mood. This data can also be used to update the environment. The closed loop treatments that we develop and validate at Neuroscape will be more powerful in virtual reality or augmented reality environments, because the connection between the individual state and the richness of the environment that they're exposed to will be greater."

An example is Healium, a Missouri-based company that uses VR and AR in combination with biofeedback to let users manage stress. Powered by devices such as smartwatches or EEG-sensing headbands, it captures bio-data in realtime to construct virtual environments. Changes in the user's brain waves or heart rate are reflected in the virtual environment. It trains users to manage their mental states by controlling the environment around them building on the metaphor that one's thoughts shape their reality. "Healium is a self-awareness tool. It is a reminder that our thoughts have the power to control things not only in the virtual world, but the real world as well", explains Sarah Hill, the CEO and co-founder of Healium.

She notes the relevance of Healium during the pandemic:

> "This is the 'Stress Olympics' right now and not everyone has trained for it. Healium is like a tool in your mental health hygiene cabinet that quickly takes you someplace else, downshifts the nervous system, reminds you to breathe, reminds you to create a stored memory of something beautiful in your head that you can recall in a situation that has value. There is no better time than right now to have some non-harmful coping mechanisms such as the one Healium provides."

Healium is being deployed to the frontlines for health care workers, who are reporting upwards of a 50% reduction in anxiety and other PTSD related symptoms.

Healium is an example of consumer-facing VR product that does not require the oversight of a clinician. A number of mindfulness, relaxation, and mediation related VR experiences are now available to

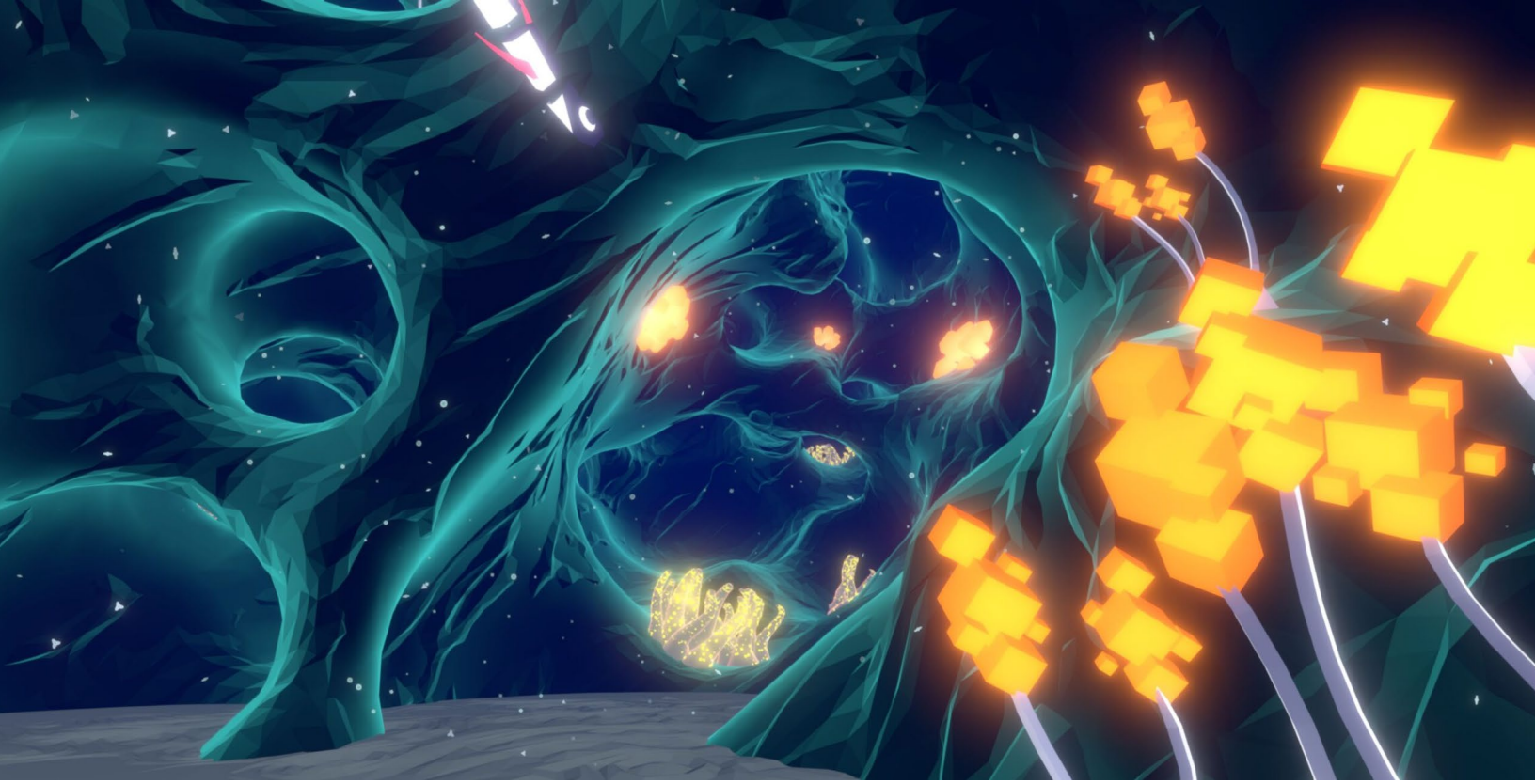


FIGURE 3 DEEP takes users on a meditative journey through beautiful underwater worlds. *(Source: DEEP)*

consumers to alleviate stress and anxiety. Studies have shown that combining VR with biofeedback sensors can reduce anxiety and increase mindfulness.[31]

Another tool that's helping combat the high prevalence of anxiety and stress in the general population is DEEP, a meditative VR experience that also uses biofeedback technology. Users find themselves immersed in a tranquil, underwater world where they are guided to breathe slowly and deeply. Such guided breathing exercises are shown to have a relaxing effect on the body. A sensor wrapped around the diaphragm of the user helps measure their breathing patterns, changes are reflected inside the virtual environment that provides users real-time feedback on their progress.

Tools such as Healium and DEEP are effective self-care interventions that facilitate in the development of skills required to cope with negative feelings or stimuli and improve overall mental wellbeing. The added benefit of staying at home, gives individuals more agency in managing their own mental health. Overall, VR psychological therapies may be a great tool to improve mental health. These therapies can be accessed from anywhere, anytime. They are more engaging which results in a higher adherence rate to protocols. It offers confidentiality to patients in a way that traditional therapies are unable to. Patients reluctant to engage in face to face therapy can discuss sensitive topics such as sexual health anonymously in such a setting. It also helps in removing the social stigma that may be associated with therapy.

4.
Anatomical Visualization

Medical errors are the third leading cause of death in the United states and a major problem to public health. A Johns Hopkins study claims that medical errors lead to 250,000 deaths every year in the United States alone.[32] Other similar studies report a fatality rate as high as 440,000 deaths per year.[33] XR can play an important role in minimizing the chance of errors due to medical negligence, for example through improved visualization of patient information for preoperative planning, intraoperative navigation, and even clinic consultation.

Doctors have depended on using spatial reasoning skills to convert 2D representations (such as X-rays, CT scans, and MRIs) into accurate 3D mental models of the human form, which can tax memory, attention and cognitive systems of the brain.[34] The chief of pediatric surgery at the University of Minnesota Masonic Children's Hospital calls X-rays "an imperfect road map of the human body," and equivalent to looking at a map on your smartphone and converting it to 3D in your mind. "Like any other road map, an X-ray image is an

FIGURE 4 XR allows surgeons to visualise patient information in 3D in real time. *(Source: Microsoft)*

incomplete reduction of reality that can misrepresent challenges or include distortions," he notes in a *Washington Post* interview.[35] XR on the other hand, is able to represent information spatially by leveraging our vestibular and proprioceptive senses and effectively engaging the multiple learning systems of the brain.[36] This approach is closer to how humans see and interact with the world versus looking at X-rays on a backlit screen. The Body VR: Anatomy Viewer and Precision VR is an app that helps create interactive three dimensional representations from two dimensional patient specific data such as CT scans and MRIs.

In preoperative surgery planning, XR can help a surgeon to visualize organs to scale in 3D and to view virtual organs from all angles to devise an ideal surgical approach. Surgeons at the University of Minnesota Masonic Children's Hospital in 2017 used VR to visualize the surgical separation of conjoined newborn babies and to "virtually embed themselves inside the walnut-sized organs as if the infant's anatomy had been blown up to the size of a living room."[37]

It is also used by surgeons for intraoperative navigation. XR is able to enhance a surgeon's vision during procedures by augmenting 3D cross sections of a patient's anatomy in real-time, eliminating some guesswork and allowing for greater precision. Surgeons can seamlessly integrate relevant patient information, such as vital signs, to avoid having to look away from the operating table to check monitors.

Platforms like Medivis, OpenSight, and Augmedics help doctors to better visualize patient anatomy to assess and refine surgical plans. In effect, doctors can look through the patient's skin to see tumors or organs in 3D, even allowing the surgeon to walk around to view them from all angles. Often during complicated cases, surgeons have to seek remote assistance from experts. Products like Proximie, ScopeAR and Avail, allow surgeons to remotely collaborate with experts without losing focus on the patient, eliminating the barrier of distance.

Similarly, medical facilities, such as the JFK Medical Edison Centre, are using VR to educate patients. Prior to surgery, patients can take a VR tour inside their bodies, in 3D and 360-degrees. This enables them to better understand their anatomy, clinical situation and surgical risk and make a more informed decision about undergoing a procedure.[38]

Medical assistance and planning is one of the most promising frontiers of XR applications in 2020. XR brings a much-needed change to how doctors visualize patient information before and during complex procedures. This helps in streamlining the surgical workflow and improving precision and safety. It also helps patients better understand their own medical condition resulting in a positive impact on patient satisfaction.

FIGURE 5 Osso VR allows hand-on-learning with surgical procedures. *(Source: Osso VR Inc.)*

5.
Medical Education and Training

XR is also being used to overcome the challenges of medical education and training. Justin Barad is an orthopedic surgeon and the founder of Osso VR, a leading surgical training and assessment platform. He has identified two core problems that surgical residents face. First, there is simply too much to learn: procedures that healthcare professionals are expected to perform at a moment's notice have greatly expanded. "When a procedure comes in, you have a one hour heads-up, sometimes maybe even less. Surgeons don't have a lot of time to prepare. You never know what you're going to encounter, and it may be something that you've never seen before," Barad explains.

In addition, modern surgical procedures are becoming increasingly complex. Traditional surgical procedures, such as a total hip-arthroplasty, might require a learning curve of 10-to-20 cases before a surgeon reaches proficiency. But newer technologies and increasing complexity might increase this to 50 or more cases. "A lot of the ways that we train haven't changed at all to accommodate this longer learning curve," Barad adds.

These shortfalls leave many healthcare professionals unprepared to perform complex surgical procedures and puts patients at an increased risk. A recent University of Michigan study found that 30% of graduating residents felt unprepared to operate without somebody supervising them.[39] XR training can address some of these deficiencies. Platforms such as Osso VR allow residents to access a library of over 70 surgical simulations, train from any place in the world, and repeat as frequently as necessary. Training modules encompass multiple specialties spanning orthopedics, pediatrics, cardiology, trauma, vascular surgery and thoracic surgery. Several teaching hospitals (such as the ones at UCLA, UCSF, and Hospitals for Special Surgery) use Osso VR as part of their training curriculum. To assess proficiency in a procedure, Osso VR calculates performance metrics such as time, accuracy and knowledge of the procedure. Since surgery is collaborative, the platform allows a team to train together remotely for procedures. Barad explains that "now that we're dealing with this new challenge of COVID-19, it is very difficult to train how we used to, which is typically at large scale courses and conferences. The ability to train remotely without being in close physical proximity is another very powerful ability of VR." A recent study shows that Osso VR improves surgical performance by 230-300%.[40]

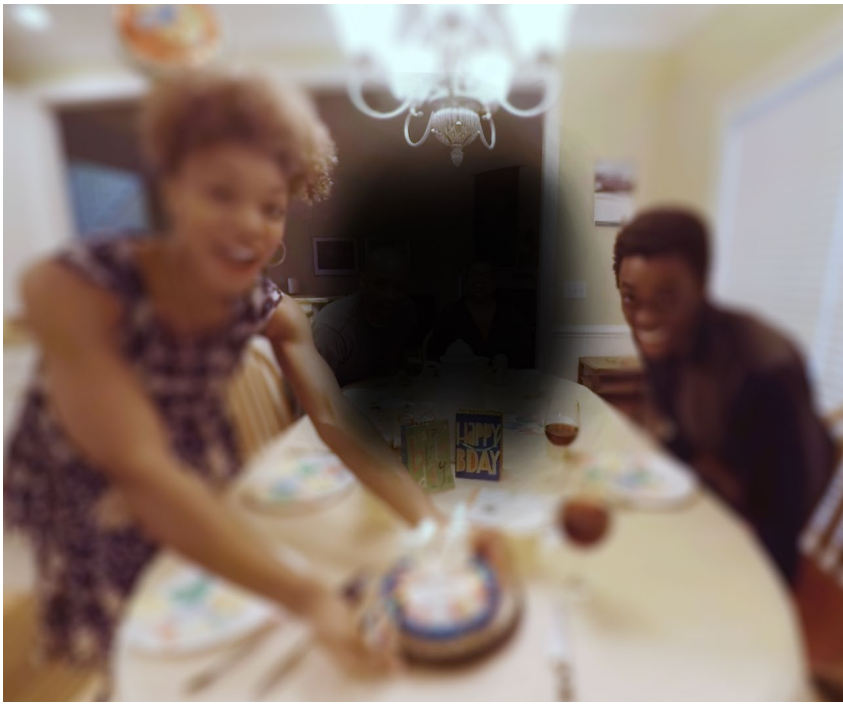


FIGURE 6 Embodied Labs lets users experience vision loss due to age-related macular degeneration.
(Source: Embodied Labs)

The constant evolution of healthcare makes medical training an extremely challenging area. Baby boomers (the population over the age of 60) are expected to make up a significant portion of the U.S. population by 2030.[41] Medical resources and practices are expected to adapt to this change as well. VR training is a practical and effective method to ensure the aging care workforce is able to meet the medical demands of such a diverse population.

Embodied Labs is one such VR training platform that allows healthcare professionals and family caregivers to understand the experience of patients facing aging through virtual embodiment. In this way, they experience the struggles of growing old firsthand, increasing empathy, and gaining better knowledge and understanding of the impact of chronic diseases such as Alzheimer's, Parkinson's disease or Lewy body Dementia.

Carrie Shaw, CEO and co-founder of Embodied Labs, describes one such module:

> For instance, in Dima Lab, the user embodies a patient with Parkinson's disease, and they have been writing with a pen normally, but they experience something common to people with Parkinson's, which is that their hands close in a fist and freeze. So while in real life your mind says to open your hands, keep writing, you're seeing that your hands are locked."

The intent is to have the user feel the disconnect one faces between the mind and the body when suffering through such a condition. The experience is elevated through the use of natural hand tracking, gaze tracking, and voice recognition to facilitate a perspective-shift toward the patient. 150 organizations use Embodied Labs modules for this type of training, including medical schools, nursing education institutions, providers of home care, hospice, senior living centers and even municipal governments.

Besides facilitating the transfer of skills and improving competency in healthcare professionals, immersive simulations helps explain health conditions and treatments to patients by simplifying complex concepts. This makes XR not just an effective tool to educate doctors, but also patients. Funded by the National Science Foundation, IKONA Health is an educational VR platform aimed at improving patient education regarding kidney diseases before, during or after medical treatment.

Tim Fitzpatrick, CEO and co-founder of IKONA Health, describes the role of health literacy in facing the challenge of helping patients transition from medical centers to in-home care.

> The future of IKONA has a lot to do with community-based education for chronic diseases. There are an estimated 40 million Americans who have kidney disease today, yet 90% don't know they have it. That's a staggering number. Many folks have no idea until it's too late, and too late means their kidneys fail, and they end up on dialysis. So the opportunities we see are how do we reach people in the community, and provide them the tools they need for educating themselves? And that's where the next evolution of IKONA will be."

Health literacy can mitigate or prevent the onset of a disease or health condition. XR helps equip individuals with formal or informal healthcare tools to monitor their health, making them active agents in managing health problems. In conclusion, XR may be a great learning tool for both patients and doctors. Todd Maddox, a scientist at IKONA health, summarizes this well: "XR is essentially a learning machine. It is able to engage multiple learning centers of the brain in synchronicity that helps not only understand information better but retain it for a longer time. This facilitates the learning of information at a very fundamental level, helping both doctors and patients achieve preferred outcomes."

6. Physical Fitness

It is well known that regular exercise can reduce the risk of developing heart disease—one of the leading causes of death in the U.S—by increasing the efficiency of heart, lungs, and blood vessels. XR fitness apps provide a great supplement to traditional exercise regimes, through gamification that makes exercising more fun and engaging. A study reported an increase in enjoyment and intensity of physical activity when performed in immersive virtual reality training devices

FIGURE 7 Supernatural transports users to scenic locations and makes working out more engaging. *(Source: WITHIN)*

FIGURE 8 Physical therapy sessions become more engaging with NeuroRehab VR. *(Source: NeuroRehab VR)*

such as Virtuix Omni.[42] The Austin-based Virtuix recently released Omni One for home use: an omni-directional treadmill that allows users to walk or run inside virtual environments. Users are strapped safely at the center of the platform and can explore virtual worlds moving in 360-degrees. Users can perform long cardio sessions disguised as VR games, encouraging them to be more physically active.

Since the body is more actively engaged in VR games than flat interface games, several companies have started working on VR calorie-tracking apps. The VR Institute of Health and Exercise (a ratings organization created to study the health impact of virtual and augmented reality) has an app called VR Health Exercise Tracker that calculates the number calories burnt per minute as people expend playing VR and AR games.[43] Research indicates that exercising in VR is comparable to exercising at a gym.

Beat Saber is a popular VR game that is used as a workout routine by many. In 2018, Robert Long claims to have lost 138 pounds in only two months from daily 30-minute *Beat Saber* sessions.[44] Similar to *Beat Saber*, *Supernatural* is designed specifically for working-out in VR. Through their expertly coached daily workouts and energising music catalogs, *Supernatural* is able to motivate users into working out by virtually transporting them to beautiful locations. Black Box became the world's first VR gym opened in San Francisco in 2019. Black Box uses virtual reality games to trick users into performing physical movements that expend a lot of energy. The team at Black Box believes that VR can turn "working out from a chore to an addictive video game".[45]

When interacting using digital self-representations (or avatars) inside virtual worlds, users experience the so-called Proteus effect, where behavioral changes made to avatars in the virtual world are transferred to the real world. A study reported that watching one's avatar exercise in VR increased physical activity in users in the real world and were effective instigators of healthy behavior changes.[46]

This effect is now being explored to promote motor rehabilitation in people suffering from traumatic brain injuries, spinal cord injuries, strokes, or multiple sclerosis. Traditional forms of physical therapy have limitations: constant repetition of movements may lead to patients feeling disengaged and low adherence to physical therapy sessions.[47] Physical therapy

sessions supplemented with VR training however have been shown to offer more engaging experiences for patients with motor impairments.[48] Patients embody an avatar inside a VR environment and are assigned physical tasks. To move the avatar, patients have to reproduce optimal motor patterns in the real world. Skills acquired in the virtual world translate directly into improved activities of daily living performance. For instance, Neuro Rehab VR is an FDA approved VR application that is used by physical therapists across the country to rehabilitate patients inside virtual environments.

Veena Somareddy, Co-founder of NeuroRehab VR notes that,

> "The biggest barrier for patients is mental not physical, patients who have had a stroke or a brain injury get stuck due to the internalization of their inability. When they're immersed in VR they look at healthy limbs of an avatar and not their actual limbs...The biggest benefit of VR is that it helps patients forget about any boundaries they might think they have."

VR programs for motor rehabilitation have been shown to favorably support the plasticity of the brain[49] that aids in the recovery of motor function. XR can be used to deliver relevant and meaningful simulations that help improve range of motion, posture, strength, balance, coordination, flexibility, and cardiovascular endurance in individuals for the purpose of rehabilitation or general fitness.

7.
Healthcare Conclusion

XR is offering solutions to many challenges of the healthcare system. It enables better access to high quality healthcare services by extending the capacity to provide care from a distance. XR enabled remote consultation helps make up for a shortage of clinicians, while affording more organic patient-doctor interactions. It is lowering the cost of healthcare by reducing time spent in hospitals. It provides a drug-free alternative for pain management and cognitive restoration. It also expands the range of tools available to monitor and manage one's own health. It incentivizes healthy behavior, explains conditions to patients, thereby improving patient experience. It helps limit medical errors by augmenting the capabilities of health practitioners, providing over the shoulder coaching, and training doctors of the future.

Despite the clear benefits, issues of safety, cost, and implementation need to be addressed for XR to scale up. More longitudinal evidence on the effects of XR needs to be gathered. No insurance company currently covers the cost XR enabled therapies. Healthcare devices are subject to a regulatory review process from the FDA before going to market, requiring time-consuming scientific evidence that demonstrates the safety and efficacy. The lack of an infrastructure to train health practitioners in use of these novel technologies may also be a barrier.

Regardless of these hurdles, the future of XR remains bright. Reduced cost of hardware is likely to draw more interest from healthcare providers, and in turn encourage various stakeholders to devise better deployment strategies. As more evidence gathers, insurance companies will likely support XR medical interventions. The integration of eye tracking and biometric scanning with XR will yield better assessment and diagnosis of patients, leading to more personalized medical interventions and a quicker road to recovery. As use of these applications in healthcare continues to grow, XR will play a major role in providing accessible healthcare.

XR for Education

OUR EDUCATION SYSTEMS have been evolving for centuries and a number of digital technologies have been successfully integrated into classrooms to improve learning outcomes. Technologies thus far have enabled better access to information. Access to information, however, is not the same as learning, just as "being in school isn't the same as learning".[50] Improving the quality of learning is also crucial. According to World Bank research, the world is facing a learning crisis. Their latest research shows that the productivity of 56% of the world's children will be less than half of what it could be if they enjoyed complete education and full health.[51] The healthcare crisis is also invariably linked to the poor performance of the education system,[52] as noted in the previous section.

Concern for the quality of education is not new. Traditional didactic teaching methods assign students a passive role in the process of learning and offer little crossover of skills into the real world. They focus on providing information and assess learners on fact retention. However, information consumption or memorization are inadequate indicators of learning when assessed in isolation. The ability to process, consume and memorize information is limited by the demand for our mental capacity, or cognitive load. The process of abstracting meaning from words, for example, requires a lot of mental effort. Subjects such as history and physics depend on students' abstract thinking skills to convey concepts. Since students may have different learning styles and learn at different rates, those who have yet to develop the stamina for abstract analyses might easily disengage and become bored in class. Such type of cognitive overload inhibits students from learning. Since school is the primary place where a student learns values, attitudes and skills that shape their personality, schooling without learning is a wasted opportunity.

As new studies on the benefits of integrating XR into classroom curriculum emerge, they bring with them hope to transform the classroom experience to ensure a richer learning experience for students. Although still nascent, XR will be a useful tool in addressing the learning crisis by transforming how students interact and learn about the world, catering to needs of students with different learning styles, motivations and cognitive capacities.

1.
Motivation and Engagement

Students need engagement and motivation for education to succeed. Yet more than half of students in Gallup's student poll reported being either not engaged (29%) or actively disengaged (24%) in school.[53] COVID-19 has forced education providers and students into their homes and disrupted standard education. As schools and universities struggle to develop teaching strategies that can be delivered online, student motivation and engagement has dropped to an all-time low. A survey conducted by the NASFAA (National Association of Student Financial Aid Administrators) of 30,000 college students indicated that 70% of students lack motivation for online learning during the current pandemic.[54] This is concerning since pre-pandemic dropout rates from online courses were already high, at 40-to-80%.[55]

Dan Ayoub, general manager for education at Microsoft, notes that

> "There've been some silver linings to all of this. Education technology has advanced several years in the course of a few months. There's been a number of distance learning technologies available, but people have been hesitant to try just because they haven't really had to. Now, all of a sudden, there's this necessity where folks have to start getting a little more creative and doing things a little bit differently."

Ayoub (who also oversees Microsoft's STEM efforts for K-12 and higher education) further explains that "when it comes to student engagement, video is not the ideal technology to be used for education delivery, especially as the pandemic has forced people remote." AR and VR on the other hand are better suited to provide experiential education remotely. "It fosters a sense of togetherness. Unlike two people staring at a screen, it lets you cohabit a virtual space together," he says.

Since the social aspect of campus life contributes to a student's academic motivation and overall well-being, VR classrooms that use avatars can create shared, immersive environments that facilitate more organic interactions. This form of online learning actively engages students versus passive consuming

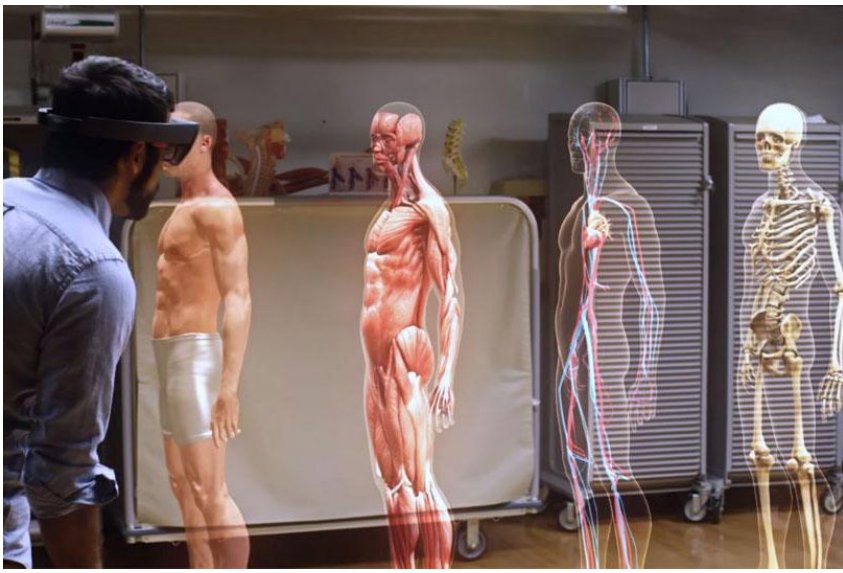


FIGURE 9 Holographic representation of different layers of the human body for teaching medical students. *(Source: Microsoft)*

of information from screens. Students at the Case Western University for instance are using Microsoft's HoloLens to learn about human anatomy remotely. The university shipped HoloLens to all 185 first year students, across 11 different countries. Using the HoloLens, students can navigate a 3D representation of a human body in 3D, view layers of skin, muscle, blood vessels, and organs, down to the skeleton. Although viewed in isolation, the experience also allows students to feel more connected to peers.

"Immersive media has the power to democratize education" says Julie Smithson, the Chief Education and Learning Officer at MetaVRse. "XR will impact education greatly through immersive technologies for remote learning [in response to COVID-19]...the next steps into immersive lessons are through XR." Smithson has been researching the importance of curiosity as a key to effective education: "The education system, the curriculum, and the teaching methods will be steered by the students and their interest to learn," she emphasizes.

Motivated, self-directed learners do better academically. Engaged students are 2.5 times more likely to get better grades and do well in school, and they are 4.5 times more likely to be hopeful about the future.[56] Research from the University of British Columbia identified three factors that increase motivation in students: personal relevance, choice and control, and mastery.[57] XR is well-suited to address

these factors. XR makes learning more immersive and interactive. Being immersed inside an interactive simulation can make abstract concepts taught in physics and history classes relevant to the real world. Students become active agents in their own learning by moving through modules at their own pace. Gamifying lessons in classrooms increases curiosity, promotes engagement, and provides a positive response stimulus that helps students progress towards mastery.

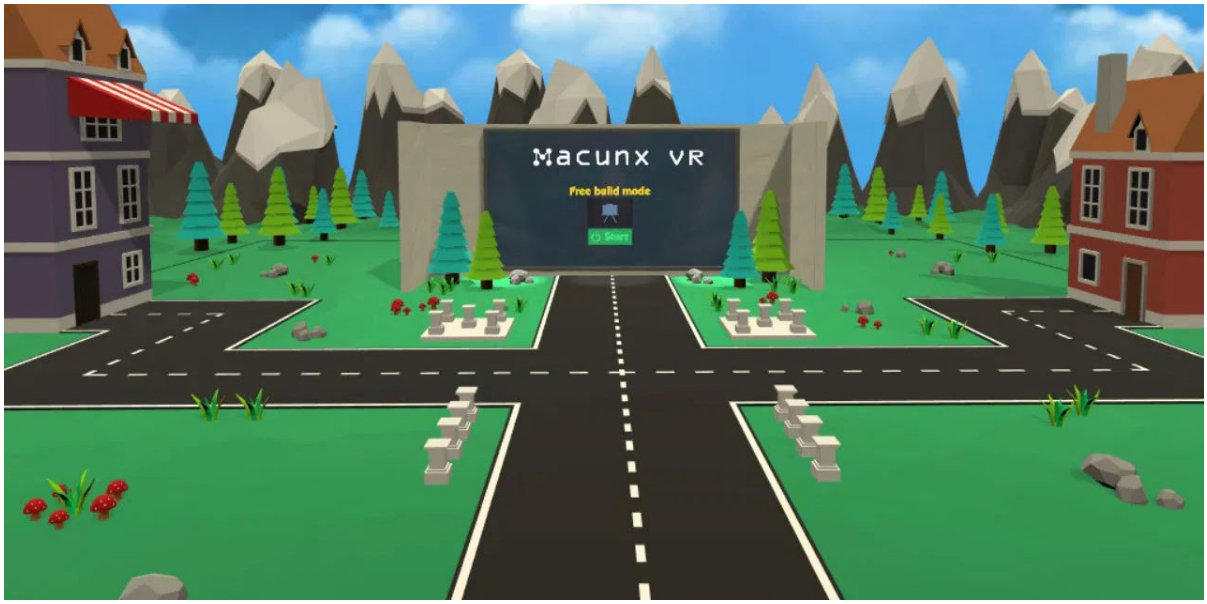
2.
Cognitive Load Reduction

XR can shorten the time it takes to acquire knowledge acquisition versus traditional means, according to Ayoub. "The grades go up, retention goes up, and engagement levels go up. Science certainly suggests that there's a lower cognitive load on the human brain using this technology." The human cognitive system includes areas of the brain dedicated to attention and working memory. Since learning involves great effort, the cognitive system is vulnerable to overload. This is particularly true for STEM topics like physics, chemistry, biology, or earth science that require high level abstract thinking. Additionally, these subject areas are taught to students through text, illustrations or videos. This may be cognitively limiting since the brain naturally organizes and remembers information spatially, it has to do extra work translating 2D static or abstract information (such as images or text) into dynamic 3D, real world representations. If subjects are taught at a rate quicker than what a student can process, it can result in poor retention. Additionally, the cognitive system is slow to develop and does not reach maturity until individuals are in their twenties.[58]

Because it is immersive, VR can promote focused attention. Research at University of California, San Francisco, reveals that selective attention performance is enhanced in young adults when using a VR platform, as opposed to a traditional 2D computer monitor.[59] Adam Gazzaley at UCSF indicates that this has been verified by research:

> "...being in an immersive environment created the context for more focused deployment of attention, and almost all the measures of attention were greater in a head mounted display VR setting than the same testing done on a 2D screen. This sets up the basis for hypothesizing that the outcomes of an intervention designed to improve cognition may be greater in that type of environment."

FIGURE 10 Memory Palaces in Munx VR, formerly Macunx VR. *(Source: Munx VR)*



Visualizing complex subjects using XR also improves working memory by enhancing spatial awareness. XR engages the vestibular and proprioceptive senses of the body in ways 2D media cannot. Since the brain naturally tends to organize information spatially, XR allows better recall of information. Researchers at the University of Maryland analyzed memory recall inside VR environments using a virtual mnemonic device, and determined that recall accuracy was improved when using VR versus a 2D desktop screen.[60] Participants immersed in VR environments could recall larger amounts of information using VR 'memory palaces' a way to remember information using spatial mnemonics.

Munx VR, formerly Macunx VR, is an application where users create their own virtual memory palaces. By placing information around in an environment familiar to the user and associating visuals with semantics (using images to help remember non-visual things), users may memorise language, anatomy, periodic table, Chinese characters etc. By mentally revisiting the environment constructed inside VR, a user can better recall and retain information. [61]

Cognitive load can also depend significantly on 'cognitive distance': the gap between how information is presented and the context in which it is applied.[62] For instance, learning about the movement of electrons through textbooks might fail to impart a robust conceptual understanding in students. Interactive VR simulations, on the other hand allow students to scale down to a quantum level to study the flow of electrons and their interaction with the surroundings. This helps anchor the student's understanding of intangible concepts. By enabling students to experience things firsthand, VR helps close the gap between concepts learned in a classroom and their applications in the real world.

3.
Experiential Learning

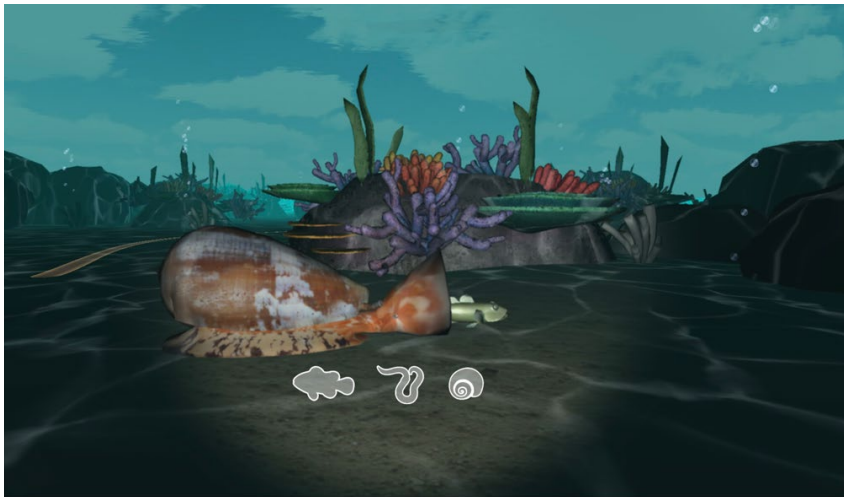
Cognition is inherently embodied. In contrast to common instructional theories that separate mind and body, embodied cognition shows that body must be part of the learning process, not just the mind. Since body movements, such as gestures, can facilitate cognitive activity, interacting with objects inside virtual environments can benefit learning.[63]

XR is especially effective at enabling 'hands-on' learning, often referred to as experiential learning. Since the brain tends to remember what it experiences better than what it hears or sees, XR allows students to absorb concepts, ideas and events by experiencing them firsthand. XR harnesses the power of multi-sensory learning and creates a strong sense of psychological presence.[64] Students can manipulate objects inside virtual environments using hand controllers and haptic feedback devices, providing a sense of agency. Hand tracking VR setups allow for more organic interactions with the virtual world.

Hope Academy High School in Indianapolis takes students on a virtual field trip to Redwoods in California to teach students about the process of photosynthesis.[65] Using controllers, students can travel inside trees or plants and see the process from inside. Gamification of such VR experiences lets students become the chloroplasts themselves and enact photosynthesis. Students explore, identify, and experiment in these environments for improved conceptual understanding.

XR creates learning contexts that engage the body, not just the mind. Students can interact with content, objects or events that might not be possible in the physical world. From venturing back into history to diving into the molecular structure of the human body to exploring the solar system, XR transforms abstractions into perceptible representations.

FIGURE 11 Experience and study underwater ecosystems using BioDive VR. *(Source: Killer Snails LLC)*



Portable and non-tethered XR devices can make it possible for students to access these experiences from any location, anytime.

Situated or experiential education is also effective in facilitating transfer of knowledge.[66] Transfer of knowledge, which is one of the hallmarks of true learning[67] enables a learner to recognize how the information or knowledge acquired in a learning environment can be applied in a real world context. XR learning environments facilitate acquisition of transferable skills by allowing students to put theory into practice. They gain proficiency at tasks that require repetition inside the safety of virtual environments, avoiding any potential dangers of the real world.

BioDive VR is developed by Killer Snails, an educational game start-up that creates digital and virtual reality games that help bring science into K-12 classrooms. This virtual reality experience (funded by the National Science Foundation) enables middle school students to explore underwater ecosystems as if they're marine biologists, learning how biotic factors and abiotic factors impact marine biodiversity in different parts of the world.

"We really wanted students to feel as if they are scientists going on expeditions," says Jessica Ochoa Hendrix, CEO of Killers Snails. Using a digital science journal, students note down observations, hypothesize and make predictions. Students are then transported to an underwater expedition to test their hypothesis. The experience exposes students to potential science careers. A dashboard lets teachers keep track of student progress inside the VR experience to assess learning outcomes. Hendrix and her team plan on making the experience more collaborative with students teams working together to solve game-like experiences. *BioDive* VR requires only a smartphone and a $15 Google cardboard to run and is being piloted in classrooms in 26 states.

4.
Personalized Learning

Students have varying learning styles or preferences, such as visual, auditory, tactile or kinesthetic. In classrooms, however, students often have to follow the instructors preferred style of teaching versus their learning style. XR however can provide personalized learning environments, improving on 'one size fits all' learning approaches, tracking individual student performance as well. XR devices can capture key performance indicators to track individual progress. Applied ethically, teachers can address problem areas where students need extra help.

FIGURE 12 Personalize lesson plans for individuals with Autism Spectrum Disorder (ASD). *(Source: Floreo Inc.)*

This is particularly beneficial for students with learning difficulties or disabilities and who require individualized education plans (IEPs). Learning in the safety of a virtual environment can help students with ADHD[68] or autism to assimilate knowledge conducive to their learning style and pace. Students can spend more time on subject matter they find difficult or proceed more quickly. Through self-directed learning students can cultivate behaviors, values and attitudes in a safe and controlled manner.

The United States Department of Education's Office of Special Education and Programs invested $2.5 million in 2019 toward a new program that will use VR to nurture social skills in students with disabilities.[69] VOISS (Virtual Reality Opportunities to Implement Social Skills) is developed by researchers at the University of Kansas Center for Research on Learning and Department of Special Education. Using VR, VOISS places students inside various social situations such as locker rooms, buses, and classrooms. Advisors and teachers support students in developing social and emotional learning by managing their reaction towards such situations. The project is planned to be piloted in 17 schools across the country.

Similarly, Floreo is a VR telehealth platform that helps support the learning preferences of students with learning disabilities. It contains a library of lessons for students on the spectrum covering a variety of social and behavioral skills, from joining a conversation that's already in progress to introducing peers to one another to how to respond to bullying. A parent or therapist can monitor a learner's progress through key performance indicators. Floreo CEO Vijay Ravindran explains,

> "We build these experiences with the data element built in. From the beginning, the data informs how to personalize and tailor content over time. Based on such metrics we're able to make lesson recommendations. The input stream that we receive from both the VR environment, and the iPad used by the supervisor, lets us tailor character behaviors. So it all comes down to having that foundation on data."

Learning tools such as Floreo, The Blue Room and Rewire can help students with learning disabilities learn new skills and concepts at their own pace and without distractions of the real world. This approach to personalized learning could also benefit students with dyslexia, dysgraphia, behavioral issues, ADD/ADHD, visual/auditory impairments, or cognitive/developmental delays. By enabling autonomy and self-directed learning, XR is an invaluable tool for teachers and students alike.

5.
Fostering Empathy

Classrooms are a microcosm of the world, where students learn not just numeracy and literacy, but values that help them become a good citizen and a better human being. Integrating XR in classrooms, with the appropriate pedagogical foundation,[70] may be transformative in shaping a student's understanding of the world. It holds the potential to promote a student's understanding and respect for human rights, different cultures, and their social environments.

If the mind and the body are inextricably linked in shaping cognition, so too they are linked in shaping one's worldview.[71] Changing someone's body therefore also changes their mind and their social cognition.[72] This is a foundation for embodiment therapy, where users occupy virtual bodies or avatars of people from different cultures or ethnic groups in VR environments. By embodying these avatars, users develop a sense of body ownership which in turn stimulates empathy regarding another person's subjective experiences. In this way, XR can challenge biases and stereotypes.

Dr. Mel Slater and his team of researchers at the Department of Clinical Psychology and Psychobiology, University of Barcelona, Spain demonstrated that being embodied in a body different from yours in VR can be a powerful experience. They conducted experiments where White participants occupied Black bodies. When performing tasks in neutral or positive situations, the experience cultivated empathy with lower scores for implicit racism, even a week later.[73]

"XR is in a position to help us think about how we design and reimagine our societies." according to Dr. Courtney Cogburn, assistant professor of social work at Columbia University. In collaboration with Stanford's Virtual Human Interaction Lab (led by Dr. Jeremy Bailenson) they created *1000 Cut Journey*,

FIGURE 13 1000 Cut Journey puts the viewer in the body of Mike Sterling, a black experiencing racism at various stages of life. *(Source: Virtual Human Interaction Lab)*

a VR experience that puts users in the shoes of a Black male—as a child, adolescent and adult—who experiences racism in different forms over time. "We're trying to find a way to connect you in a more personal and visceral way to the realities of racism," says Cogburn, who has been studying the long-term health effects of such VR experiences on people over time.

> "Do their beliefs shift? Do they analyze problems of race in society differently? Are they changing their behaviors or are they changing the ways that they reflect on themselves as a result of going through this VR experience? And we're finding evidence that that is certainly the case and it's happening not just for White Caucasians, in fact, we're seeing it across multiple racial groups who have been through the VR experience."

She and her team have also been working with educators and instructors to integrate the VR experience into school curriculum.[74]

Graduate students from Stanford University have also developed *Becoming Homeless: A Human Experience*, a VR experience where participants embody a jobless homeless person who is selling personal belongings to make ends meet and seeking shelter in the subway. Even after eight weeks following the experience, participants showed greater approval for aid for the homeless versus those who did not have the experience. The findings provide longitudinal evidence of VR's efficacy for cultivating empathy and impacting positive social change.[75]

Embodying experiences in XR has shown to elicit distinct affective responses in young adults, effects of which carry over to the real world. When used ethically, this learning affordance can be used to build empathy and a greater understanding about people, situations and events.

6. Cost Reduction

The cost of XR has previously been a barrier to its use in education. As XR becomes more economically accessible and user friendly, it has made inroads into classrooms and holds the potential to democratize education by providing students from all backgrounds an accessible learning alternative. However, there are still significant financial obstacles that need to be accounted for before this technology can be adopted at a scale that can benefit underserved populations.

FIGURE 14 Realistic and interactive laboratory simulations using Labster. *(Source: Labster)*

"XR is helping bring equity in education," says Steve Grubbs, CEO of Victory XR which creates immersive educational experiences for schools across the United States.

"STEM labs are great additions to schools and a huge asset to students, but it may take up to $2 million to set up a state-of-the-art lab in schools," he explains. Schools in lower economic communities often have budget restrictions that lead to an unequal distribution of equipment. As STEM occupations grow in the U.S. —11% by 2026 according to the forecast bureau of Labor Statistics—and education and training need to help meet this need. With XR, schools can scale science labs at a fraction of the cost of 'real' labs. Grubbs notes that schools can buy 25 virtual reality headsets for $10,000 to $15,000 and purchase up to 25 subscriptions to Victory XR's Academy priced at $10 each.

Labster is another popular VR app that allows students access to more than 1,000 different virtual lab environments. Equipped with the same tools and instruments as real labs, they encourage students to think scientifically. Labster's virtually simulated labs make science engaging by exposing students to real-world choices and decisions that scientists need to make in an interactive gamified format. Grubbs identifies that these sorts of cost savings need not be limited to science labs though:

> "Not just science labs, but also astronomy centers, space transporters that take them to Mars, or a time machine that takes them back in history. ... XR really levels the playing field, it lets students explore the world in a way they cannot in classrooms. As opposed to looking at wooly mammoths at the natural history museum, students can walk among a herd of woolly mammoths and pet the baby mammoths. Instead of looking at stars in a planetarium, students can use a Star Trek-style transporter that transports them to different galaxies and stars helps them get a better sense of scale."

Grubbs's descriptions might bring to mind traditional field trips. The experience of exploring museums, theaters, or even other countries or cultures is an integral part of the learning process. Schools are often unable to provide such experiences due constraints such as time, money or the process of getting permission slips. Virtual field trips allow for experiencing places and phenomenon around the world without leaving the classroom. It can extend the possibility of situated or experiential learning in geography, history, literature or other subjects when integrated into existing curriculum and with instructional support.[76]

Google Expeditions allows students to take a virtual field trip to over 500 different experiences across time and space—such as the Great Wall of China, Machu Picchu, the International Space Station or even Jupiter—using just a $20 Google Cardboard viewer. Over two million children have experienced Google Expeditions to date. Similarly, Boulevard Arts creates art-based XR experiences for students and educators. The company has partnered with world's leading museums to make art and culture more accessible to everyone. Students unable to travel to Paris can appreciate works of Édouard Manet, Claude Monet or Paul Gauguin by putting on a pair of VR headset. Using this format they may even 'step inside' the painting or listen to narrations to guide their experience.[77]

7. Teacher Training

Although qualified teachers are the cornerstones of an effective education system, a World Bank study suggests that the lack of qualified teachers is a leading cause for the global learning crisis.[78] Their research found that a remarkable number of primary school teachers could not subtract double-digit numbers or multiply double-digit numbers in seven different African countries.[79] A separate study conducted in Indonesia found that the majority of math teachers lacked adequate pedagogical knowledge.[80] Since a successful education system is one that can effectively prepare, support and motivate teachers, a critical first step in improving the quality of education is ensuring that teachers are equipped with appropriate content knowledge and pedagogical skills to effectively transmit knowledge to students.

XR environments are well suited to providing professional development for teachers at home and at lower cost. Virtual spaces can mimic a real classroom for teachers to practice lessons, improve instruction, and encourage student participation. Challenges can be safely introduced that train teachers to better manage the classroom and student behavior. "It can be used to decouple content and pedagogy and train on these areas individually, something that can't be done in a real classroom," says Lisa Dieker, the co-founder of TeachLivE. Teachers can both develop and convey content knowledge for effective learning.

TeachLivE is a mixed reality solution developed at the University of Central Florida's Center for Research in Education Simulation Technology. Classroom simulations help teachers develop effective instruction

FIGURE 15 TeachLivE VR simulation training allows teachers to practice lessons in front of virtual students. *(Source: UCF Center for Research in Education Simulation Technology)*

and management skills in a safe environment that doesn't place real students at risk. Dieker notes that

> "The training program is similar to choosing your own adventures. You can put people in a simulator, and they can choose their own path. That is, the simulation can be customized according to the objective. A classroom setting can be designed to be very passive, or very chaotic."

Behaviour of the virtual students inside the simulation can be easily dialed up or down according to the training objective. Training objectives include asking higher level questions, improving wait times, behavior management, or providing comments. It can also help train teachers to identify students that require extra help or offer remediation for failing student teachers. TeachLive has partnered with Mursion and is being implemented in more than 100 schools.

In Massachusetts, Mursion and the Department of Elementary and Secondary Education are partnering to design and embed virtual simulations in educator preparation programs across the state. Mursion collaborated with subject matter experts to make sure the training scenarios were relevant and could be directly integrated by the educators into their courses. It designed four avatars—two with specific learning disabilities, an English learner, and an adult avatar—so teachers could practice their skills in a variety of situations.[81]

In Texas Round Rock Independent School District, school staffers use a virtual training program by Kognito to fulfill suicide prevention training that is required under Texas law. In the simulation, a user role plays a conversation with an at-risk student. Enabling educators to practice difficult conversations in this low stake situation increases their preparedness and effectiveness.[82]

The results of a two-phase study on math and biology teachers found that four ten-minute sessions (not including feedback sessions), significantly improved targeted teaching objectives. These improvements in teachers' also transferred over to real classroom settings.[83] Motivated and competent teachers produce motivated and competent students. XR can help teachers further their subject knowledge, and refine instructional, classroom management, and curricular development skills to improve learning outcomes.

8.
Education Conclusion

The benefits that XR brings to classroom and educational settings are evident. The immersive nature of XR promotes focused attention, where students can absorb knowledge faster and retain it for longer. XR environments cultivate curiosity and enthusiasm by allowing students to experience, interact, explore and experiment with content, making them active agents in the learning process. XR helps establish relevance between lessons taught in class and how they relate to the real world by providing students and teachers direct access to experiences which might be dangerous, expensive, or out of reach. Allowing students to engage in such experiential learning is also advantageous over traditional teaching approaches when it comes to facilitating transfer of knowledge.

XR has also been shown to elicit distinct affective responses in students, useful for imparting a more robust understanding of human rights, racial equity and environmental degradation. XR can provide tailored education to suit individual learning needs or preferences, with benefits for teaching social and behavioral skills to students with special needs. XR environments are also ideal for collaboration and distant learning, allowing students to interact, share and learn from one another more organically. It allows schools to scale resources, such as science labs, more easily and provide professional development training for teachers.

While the potential benefits and applications of XR in classrooms are still being explored, it is clear that best outcomes depend on how XR is rooted in an existing learning pedagogy. For instance, grounding XR in activities designed around constructivist[84] or social constructivist[85] learning theories have shown to produce the best learning outcomes. The success of XR in classrooms also depends on how it is supported by the instructional methods. Teacher supervision is essential both before and after an XR experience, first to establish expectations, and after, to guide students through a debrief process. Post-experience debrief is important to encourage students to reflect on the experience and anchor their new understanding.

Adoption of XR faces some challenges and barriers. The cost of, and access to, XR technologies still remains a barrier. Globally, many schools lack the necessary infrastructure, such as a stable internet connection, to deploy XR. There currently is also a lack of quality educational content available in the marketplace. Resources to help teachers customize content to fit their curriculum are also limited or require long learning curves, and hiring developers to create custom content may be prohibitive. XR's long-term impact on a student's health and development still needs further research. Psychological risks pertaining to XR need further exploration, with some research suggesting there may be ill-effects on cognition of long-term immersion (such as implantation of false memories) in elementary schoolers.[86] Privacy and security risks associated with data collection in XR can be a cause for concern.

Despite these obstacles, teachers and students remain very receptive to using the technology.[87] Progress of XR in the education sector seems to be at a developmental stage. The ubiquity of XR depends on how well and how soon the pain points can be addressed.

XR for Workplace Training

THE YEAR 2020 has ushered several transformations in the workplace. COVID-19 has forced entire offices to rapidly transition to remote work environments. Employers and employees have had to develop strategies to effectively communicate and collaborate remotely. Social distancing protocols have forced companies to reconsider how they recruit, train and upskill talent. Companies are also increasingly launching workplace training that addresses racial bias and diversity, equity and inclusion efforts. As companies struggle to keep up with the pace of change, several are turning to XR as a new way of addressing some of these issues.

1.
Remote Communication and Collaboration

The pandemic has made a strong case for not maintaining physical offices. However, working from home can be challenging to a sense of a shared environment, and organic interaction among remote teams. Current alternatives to face-to-face communication such as emails, video conferencing, and messenger apps fail to deliver a full range of social cues between the speaker and the listener. In addition to the spoken word, the brain derives meaning from nonverbal cues such as eye gaze, facial expressions, hand gestures and body postures. Without this, there can be a dissonance that affects employee morale and productivity. A 2020 State of Work report[88] indicated that 20% of remote workers regarded remote collaboration and communications as the biggest challenge to working from home. Another 20% listed loneliness as their biggest struggle. XR may offer ways to address both these issues.

XR virtual environments allow remote teams to occupy a shared virtual space, with the same agency and presence as in an actual conference room. Attendees appear as avatars in such XR meetings. Non-verbal cues such as lip motions, facial expression and eye movement, as well as body movements, may be captured using XR hardware. As a result, remote work takes on a more natural feeling and teams can better share knowledge, exchange ideas and seek solutions faster.

For example, Spatial's AR remote collaboration software uses XR to populate shared virtual workspaces not just with avatars, but with digital objects (post-it notes, video screens), documents, models, images, and videos. This lends itself to brainstorming sessions, training, design sprints, or an agile scrum. Spatial believes that an intuitive UX, coupled with the right input modalities (hand gestures like waving, grabbing, tapping), and the use of design signals like color and light, can help focus the user's attention and streamline the expansive 3D space. Spatial works in conjunction with the existing workplace collaboration tools, significantly reducing the threshold for adoption by new users.[89]

The most striking feature of Spatial is its avatars. When a user signs into the platform, they are asked to pose for a quick headshot, which helps render a relatively realistic avatar for each person, reducing the need for name tags. In a medium where human connection can be challenging to achieve, this step towards realistically rendering one's avatar may be what makes users feel comfortable interacting with others and occupying the virtual space for extended periods.

Similarly, Facebook Reality Lab (led by Yaser Sheikh) has been working on a 3D capture system that allows people to create lifelike virtual avatars of themselves quickly and easily. The project is named Codec Avatars and accurately captures people, their facial expressions, and body movements to a high degree of detail leading to more authentic telepresent exchanges.

Another example is MeetinVR that leverages the power of virtual reality to combine the flexibility of online meetings with the interactivity of in-person meetings. With features such as interactive whiteboards, 3D viewings, movie viewings, and podium speeches in virtual workspaces with customizable scenic backgrounds, it aims to combat Zoom fatigue and make remote meetings more engaging. A 25% increase in attention was observed among users inside VR meeting rooms when compared to video conferencing tools.[90]

Operating with the same technology at its core is AltspaceVR, a social VR platform that lets people host gatherings such as live shows, meetups, classes and even business meetings. Through the platform, users can collectively stream content, interact, and exchange information. AltspaceVR puts emphasis on creating a virtual community that is inclusive and has most recently made its avatars more customizable to represent a wide variety of genders, races, and ages.

FIGURE 16 Spatial enables employees to collaborate remotely in a workshop style allowing a more intuitive exchange of information. *(Source: Spatial)*

FIGURE 17 Customizable crane training scenarios developed by Serious Labs. *(Source: Serious Labs)*

2.
Hard/Technical Skill Training

The rapid rate of technological innovation has created a shortage of skilled technicians across the world. The situation only continues to accelerate with the adoption of new technology and the shift in desired/relevant skills it creates. Current training models lag behind, leaving professionals ill-equipped to enter the job market. A Deloitte report revealed that 2.4 million positions may remain unfilled between 2018 to 2028 causing a deficit of about $2.5 trillion.[91] XR training models present alternatives that are scalable, cheaper and theoretically accessible from anywhere with an internet connection.

VR training is not new; the aviation industry has successfully used immersive simulations to train pilots for decades, with a 50% reduction in crashes due to human error. XR enabled training is effective in recreating workplace situations which might be dangerous or expensive, and is a good fit for chemical manufacturing, heavy equipment training, oil rigging and similar industries. XR provides a risk-free environment where workers can learn to avoid real-world mistakes with potentially fatal consequences. Workers can engage in experiential learning as often as desired, helping them gain proficiency in their skill faster.

In the automotive industry, Toyota has developed an interactive virtual learning program to train its assembly line workers. Immersed in a realistic virtual assembly line, workers go through 3D simulations of step-by-step processes that familiarize them with both hand movements and corresponding IT systems. The training becomes progressively more difficult which translates to an increasing level of independence and information retention.[92] The Volkswagen Group also recently announced a global VR training initiative, in partnership with the VR studio Innoactive, to train 10,000 employees in skills from vehicle assembly to new team member training to customer service. Employees learn at their own pace and with a more cost-efficient workflow.[93]

VR training also equips workers with job-specific occupational skills: a 2011 study from Iowa State University found that welding students who used VR for at least half of their training performed better than those who received only traditional training. Over the past three years, the Houston Area Safety Council has used VR to train welders. Similarly, ITI VR and Serious Labs collaborated on a Crane Simulation Library with over 1,000 scenarios across multiple crane and equipment models. Industrial forklift simulators are available to help operators master the equipment and understand safety protocols in a safe environment. Advantages to VR training includes access to crucial metrics (like the speed and spacing of the welds), and enabling an entire classroom to observe and give feedback.

In certain industries, effective training can be the difference between life and death. BP, a UK-based oil and gas company, partnered with Igloo vision

to train its employees at their oil refinery in Hull, England. Employees could make mistakes in a virtual environment with a lesser probability of making the same error in the real world. The plant was recreated digitally using scanning and detailed texturing. Field technicians could practice tasks such as safe startup and emergency shut-down procedures. Competence and readiness could be assessed, with increased safety and reliability. Employee skill levels and progress can be quantified by analyzing their data inside the training environments to guide feedback and work through roadblocks.

Kyle Jackson, the CEO of Talespin, elaborates on the benefits of skill assessment,

> Training in XR is like being in a game, a lot of the things that you're doing become quantifiable. Inside a training simulation, you're constantly building experience points and earning credentials...We want people to use those as ways to demonstrate their capability. This way, we can move away from standard resumes and towards a more nuanced language that communicates what someone is particularly good at or where their gaps might be, or how quickly they can fill them."

Talespin is a leading developer of XR solutions for hard skills and soft skill training. It recently partnered with PwC (the second-largest professional services network in the world) on a large-scale study on the effectiveness of VR training platforms. The results showed that employees who trained in VR completed their training four times faster than in the classroom, and were four times more focused than their e-learning peers. They were 3.75 times more emotionally connected to the content than classroom learners and were 275% more confident to apply skills learned after training.[94]

FIGURE 14 VirtualSpeech provides a safe environment for employees to improve their presentation skills. *(Source: VirtualSpeech)*

3.
Soft Skill Training

In addition to the technical skills described above, XR technologies offer an affordable, scalable, repeatable, safe and a measurable way of training and upskilling employees in social skills. Apart from effective communication, soft skills such as team work, conflict resolution, and public speaking are also important determinants of success in the workplace. This is another area that Talespin is working in; Jackson explains "One of the things that's happened is that our generation has become so proficient in communicating via text, that most find it difficult to interface with multiple generations of the workforce in-person. So effective communication has been a big focus, both communicating up and communicating down." Talespin offers a no code, self authored platform that allows organizations to create various interpersonal situations for training purposes. UK-based VirtualSpeech is another education platform that specializes in such training. E-learning courses are combined with VR practice sessions featuring realistic simulations such as conference room meetings and networking events. Employees can practice what they learn and receive instant feedback on their performance. One simulation features being ambushed by reporters and being asked difficult questions. Such scenarios lets employees manage reactions and make informed decisions even in unexpected situations.

Sophie Thompson, the co-founder of VirtualSpeech, says of their public speaking course that one might do "20 minutes of learning online which might consist of eye contact training, managing distractions, and impromptu speaking. Then users will be asked to prepare a 10-minute pitch about their company's values which will be presented in VR in front of a virtual audience of 7-20 people. Following their presentation, an AI analyzes their eye tracking data and the use of hesitation words, pitch, pace, tone, etc. All these metrics

are used to calculate a score for their performance. They can then practice further to improve their scores, even when they are working remotely. Managers may also view employees progress to identify strengths and any areas for improvement."

Soft skill training equips employees for pitching, negotiating, networking, and customer service. Strivr is a workforce training platform that develops immersive environments for large scale enterprise applications. Strivr teamed up with Walmart In 2017 which procured 17,000 Oculus Go VR headsets to train a million retail employees to learn essential skills like customer service. During a pilot run, associates using VR training reported 30% higher employee satisfaction, scored higher on tests 70% of the time, and logged a 10-to-15% increase in information retention.[95]

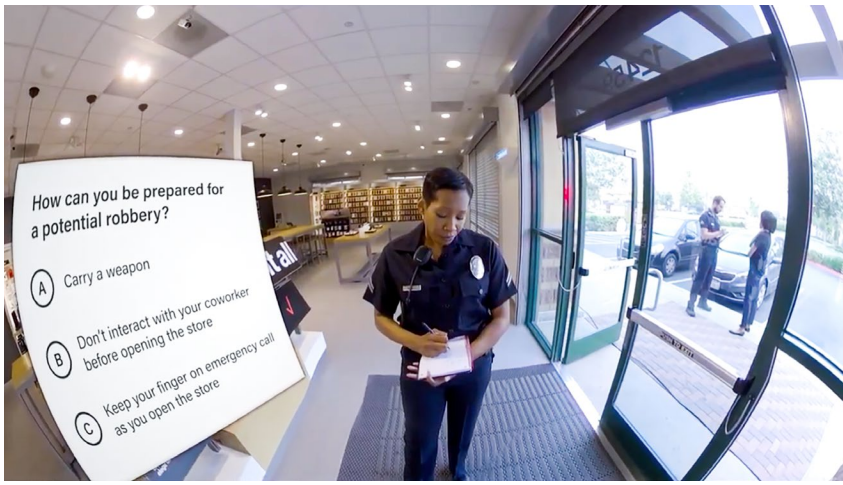


FIGURE 15 Strivr allows first responders to be better prepared for emergencies. *(Source: Strivr)*

4. Emergency Training

Having an emergency protocol is imperative for employees so that they may respond to unexpected situations safely. XR helps employees prepare for emergencies by experiencing high-pressure situations virtually and teaching them how to respond without harmful real-world consequences. Verizon used a VR training platform developed by Strivr to prepare 22,000 employees at 1,600 retail stores for challenging or dangerous situations such as an armed robbery. Associates learn critical steps to deescalate a high-risk moment. 97% of employees reported feeling prepared when put in dangerous situations.[96]

Emergency responders can minimize casualties by being better prepared for situations. XR simulations that mimic the real world enable safety protocols to become ingrained as muscle memory for responders who develop decision-making skills under pressure. Such training environments can be accessed as frequently as desired, at a fraction of the time and cost required to set up such training environments in the real world.

Several government agencies are already using VR in this way. The US Department of Homeland Security responded to the rising number of mass shootings in the United States by developing and implementing EDGE (Enhanced Dynamic Geo-Social Environment), a WebVR training simulator. EDGE helps prepare first responders and equips them with the necessary skills to respond to active shooter situations. EDGE has since been upgraded to focus on educators and school employees. This was done in response to FBI data that says that since 2000 more than one-third of all mass shootings have taken place in schools. The developers used actual dispatch tapes, police reports, and first-hand accounts of affected individuals to re-create a realistic, chaotic environment.[97]

The Centers for Disease Control and Prevention also has invested in deploying a new, immersive VR training tool that adds sounds and smells to visuals to prepare both experienced and novice emergency workers for real-world scenarios.[98] In light of the recent wildfires in California, the emergency preparedness of firefighters is at the forefront. The US Fire Administration (USFA) is also looking at VR as a safer way to train firefighters.[99]

5. Improving Efficiency & Limiting Human Error

Several modern industrial operations such as manufacturing and assembly follow complex step-by-step procedures. Naturally, workers or technicians often consult printed or electronic manuals to avoid making mistakes. For instance, while moving cargo from one place to another, forklift operators often multitask, switching their attention between

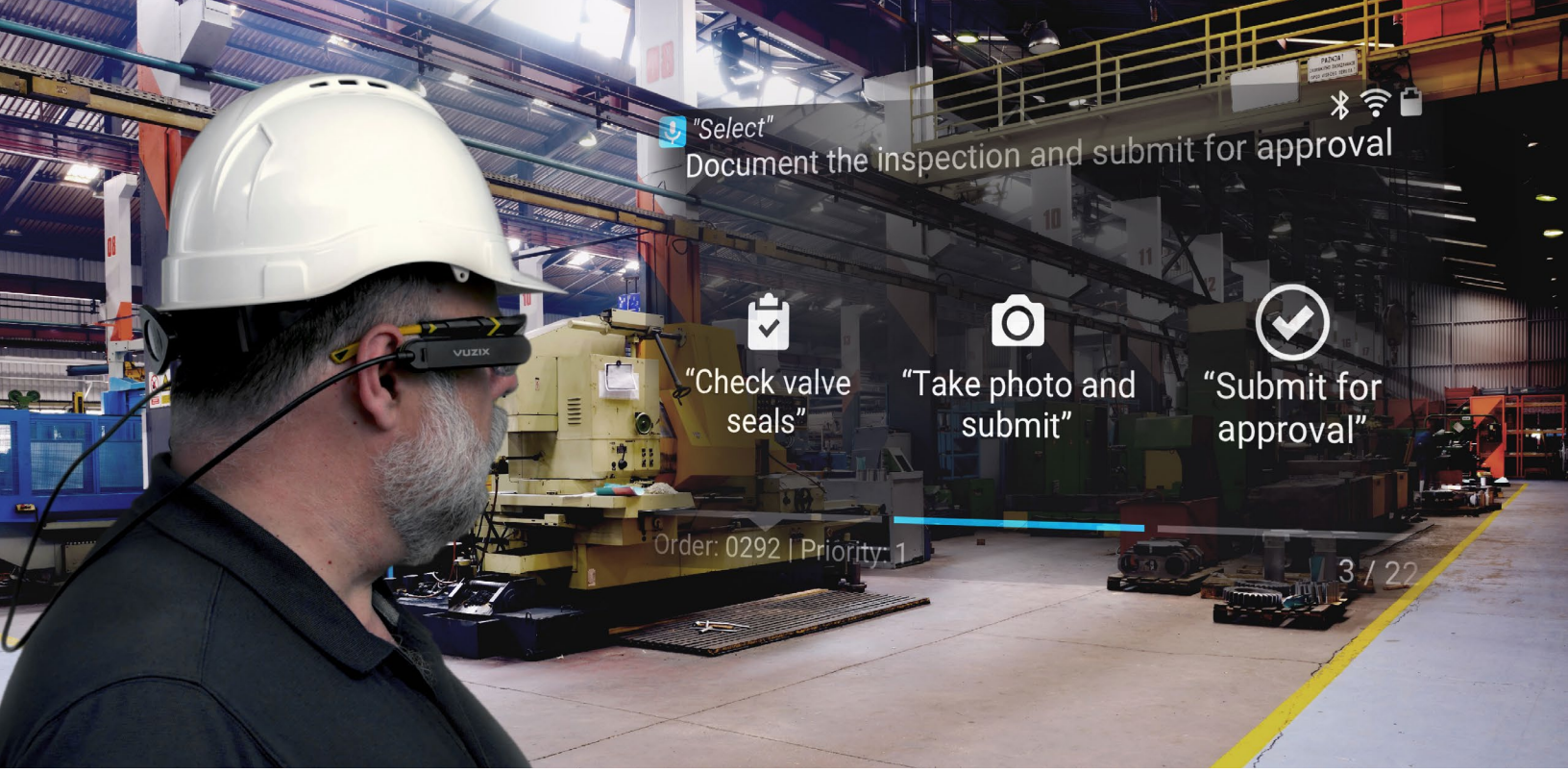


FIGURE 16 Smart glasses provide information and instructions to workers on the go, limiting the chances of human error. *(Source: Upskill)*

operating equipment and looking at printed manuals or instructions. Since a small error could cause significant delays down the entire production line, accuracy and speed are of utmost importance. Augmented and mixed reality eyewear, such as the Microsoft HoloLens allow workers to perform tasks faster with fewer mistakes by overlaying task-specific information within their field of vision. They allow instant access to technical documentation, instruction, and checklists with the additional ability to scan barcodes or QR codes. They also allow workers to view highly detailed models of equipment, scale them up, and navigate around them, all within a compact and comfortable device that can be worn on the head, similar to standard glasses. This is a more intuitive way of visualizing information and exerts less cognitive load compared to looking at images or text on phone screens, significantly reducing error rates and equipment downtime while speeding up tasks.

Upskill has developed a software suite called Skylight AR that is accessed by Microsoft HoloLens and other smart glasses to support large scale industrial operations. Skylight is used by companies such as Boeing, Coca-Cola, and General Electric (GE).[100] Boeing employs Skylight across heavy manufacturing and warehousing environments. The platform has helped GE significantly reduce errors, lower operating costs, and improve efficiency, such as its application at GE Aviation. In conjunction with Glass, it helps ensure the correct tightening of bolts in the jet assembly process, potentially saving millions of dollars. Coca-Cola is using Skylight AR globally for equipment inspection, service calls, and routine audits. Technicians wearing smart glasses can also stream, in real-time, a video feed to a subject matter expert to troubleshoot the problem without being physically present. The use of this technology saves the company nearly $10,000 every service call by not having to fly out experts.[101]

With XR, experts can provide remote guidance to field workers using a first person view of a situation via live audio and video. The remote expert can provide better information or instructions in real-time to reduce human error and improve efficiency. An example is Scope AR which creates Augmented Reality solutions for enterprise applications. Their Remote Assistance platform links workers in the field to remote specialists and makes knowledge sharing more seamless. Scope AR products are used by Lockheed Martin and Unilever.

XR has been shown to streamline workflow by providing valuable information and alerts to workers on the go. This helps improve productivity and performance while increasing safety. The possibility of an automated virtual coach guiding workers through the operations is also in sight for the future. By overlaying information on their visual field, such virtual coaches can provide insights to workers precisely when they need it. This can have a significant positive impact on task performance and workplace safety.

6.
Workplace Training Conclusion

XR has placed a novel tool that ensures a collaborative, productive, competent, and safe work environment at the disposal of organizations. It helps remote teams stay more connected and engage in richer collaborations by enabling a more intuitive flow of knowledge and ideas. XR shared spaces also create ideal environments for virtual gatherings such as meetings, seminars or conferences. Its ability to facilitate deeper connections might make it the preferred format for hosting virtual events in the future. XR takes employee training and development to its next logical step.

By simulating scenarios that might be dangerous, expensive or difficult to replicate, it allows employees to engage in experiential learning for process based tasks that require repetition to gain proficiency. In addition to technical skills, it also facilitates soft skill development that leads to better coworker, client or customer interactions. This form of training is favorable over traditional T&D programs since it results in better recall accuracy and transfer of knowledge. Several organizations and government agencies see XR as an effective tool for emergency and disaster preparedness training. Placing employees in high pressure XR simulations allows them to develop skills to respond to emergencies safely. It helps workers to contextualize and visualize information in real-time, significantly limiting the chances of human error. This results in lesser operational downtimes and failure costs thus improving overall efficiency.

Finally, XR opens up new possibilities for skill assessment. Analyzing metrics based on employee training and performance inside virtual environments, allows managers to track progress, offer feedback and talk through roadblocks. XR's ability to elicit distinctive affective responses is also being leveraged by several companies to address workplace biases. Allowing employees to experience behaviors faced by underrepresented groups helps stimulate empathy, drive reform and create a more inclusive workplace environment. Despite these benefits, a few challenges persist. The short term cost of implementation may be prohibitive for some organisations.[102] Extended use of XR may pose certain health risks such as eye strain, nausea or anxiety. A significant number of users also report feeling disorientated or 'cybersick' due to a sensory conflict that it creates.[103] Data collected from training sessions might be in danger of being misused, unless regulated properly. Organisations must navigate these challenges before bringing XR to employees and making it a standard for training or collaborating.

Final Thoughts

AS XR BEGINS TO exert a profound impact on society and culture, we are witnessing new social impact uses beyond entertainment, with XR contributing to positive outcomes in healthcare, education, and workplace training. XR can overcome the barrier of distance, enabling better access to healthcare facilities, educational experiences, or skill-building environments. It saves time by ensuring a quicker road to recovery, facilitating quicker transfer of knowledge and creating more efficient workflows. It saves money by enabling access to experiences that would otherwise be expensive, dangerous, or unavailable. It creates intuitive learning environments for visualizing information and increasing retention. Individuals can practice or learn skills without the potential of unwanted situations that may arise in real life. It makes remote collaboration feel more natural and knowledge sharing much easier. It creates emotionally compelling, memorable experiences that help facilitate positive behavioral changes.

While XR's deployment continues to expand, hardware remains a barrier to mainstream adoption. However, the cost of entry is likely to reduce drastically in the coming years. XR devices will get less bulky and more user friendly, encouraging adoption. The rollout of 5G networks should also boost non-tethered and portable applications. Additionally, the combination of biosensors with XR provides valuable data about the user that can be helpful in achieving preferred outcomes. This may help clinicians obtain a better objective assessment of patients or allow individuals to monitor their own health. It would also enable teachers to provide tailored learning environments conducive to the students learning style and pace and managers to assess employees progress and talk through roadblocks. While these developments may spark our imagination, there is still a lot of work that needs to be done before XR can reach its full potential.

Like previous emerging technologies, XR presents some ethical challenges that need to be taken into consideration. Concerns such as security, privacy, addiction, negative psychological impact, digital polarization, inclusivity and accessibility need to be addressed before this technology can proliferate. Additionally, more peer reviewed evidence and longitudinal studies are required to validate its impact. These challenges can also be viewed as opportunities, attracting resources and investment from various stakeholders (such as regulatory bodies, tech leaders, innovators, ethicists etc.) to ensure that XR is used ethically and appropriately.

A common criticism of XR technologies is the fear that they may undermine social connection through isolation. On the contrary, as shown in this paper, XR can often enlighten us, build empathy and make connections, fostering deeper understanding of one another and the world. It can help transcend the barriers of distance and time to make us feel more connected than before. In this way, XR does not necessarily need to replace existing tools or modalities, but rather can enhance them.

Although this report showcases some of the most impact-driven XR use cases, they ultimately represent just a fraction of the laudable work happening across an ecosystem that continues to expand and evolve. With the transformations that XR makes possible on the horizon, it is in our power to steer its progress in the right direction. As with all technologies, it is in the intentional design for human application that we create the potential for meaningful and positive change.

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Appendix: Companies and Experiences

XR FOR HEALTHCARE

AppliedVR - Provider of therapeutic VR for pain management.

XRHealth - XR-enabled telehealth platform for remote treatment.

SnowWorld - VR pain management experience for burn victims.

Bravemind - VR exposure therapy for treating Post-Traumatic Stress Disorder

Invite Only VR - A VR vaping prevention game for young adults.

BehaVR - VR therapeutics platform for treating behavioral addictions.

Psious - A VR therapy platform treating various phobias and disorders.

Neuroscape - A multidisciplinary research center at UCSF focused on assessing and optimizing brain function of both healthy and impaired individuals.

Healium - Self help app for managing anxiety and stress.

DEEP - A meditative virtual reality game for relaxation.

Anatomy Viewer by **The Body VR** - VR visualization for patient-specific medical data.

Medivis - Holographic visualization and navigation tool for surgeons

OpenSight - AR system for pre-surgical planning.

Augmedics - AR navigation system for surgery.

Proximie - AR platform for remote surgical collaboration,

Avail - AR platform for virtually connecting surgeons with remote experts.

Osso VR - A surgical training and assessment platform.

Embodied Labs - A VR platform for training the aging care workforce.

IKONA Health - An immersive learning platform for patients and healthcare providers.

VR Health Exercise Tracker by **The VR Institute of Health and Exercise** - App that calculates the number of calories people burn while playing VR and AR games.

Beat Saber - A VR rhythm game that encourages full body movement.

Supernatural - A dedicated VR fitness app that makes home workouts more engaging.

Black Box VR Fitness - Gym that combines virtual reality with exercising.

NeuroRehab VR - Virtual reality platform for physical therapy and neurological rehabilitation.

XR FOR EDUCATION

MetaVRse - A global XR consulting and custom development firm.

Munx VR - A platform for building memory palaces in 3D and Virtual Reality.

BioDive VR by **Killer Snails** - Combines virtual reality and digital journaling to enable students to experience the life of a scientist.

VOISS (Virtual Reality Opportunities to Implement Social Skills) - Initiative aimed at improving learning outcomes for individuals with Autism Spectrum Disorder using virtual reality

Floreo - Virtual reality lessons aimed at improving social and behavioral skills in children with autism.

The Blue Room - A VR treatment for situation specific anxiety and phobias in 7-17 year olds with ASD.

Rewire - A game based learning course for children with autism

1000 Cut Journey - An educational virtual reality experience of a black male encountering racism as a young child, an adolescent, and a young adult.

Becoming Homeless: A Human Experience - An immersive experience that puts viewers in the shoes of someone who can no longer afford a home.

VictoryXR - Virtual Reality and Augmented Reality educational content creator.

Labster - Virtual reality powered interactive laboratory simulations.

Google Expeditions - Immersive learning and teaching tool that lets students go on VR trips around the world.

Boulevard Arts - Is the leading developer of arts-based immersive reality.

TeachLivE - Mixed-reality platform for training teachers.

Mursion - Virtual reality simulation company that delivers experiential learning for essential skills in the workplace.

XR FOR WORKPLACE TRAINING

Spatial - An XR enabled collaboration platform.

Codec Avatars by **Facebook Reality Labs** - Creates lifelike virtual avatars of users for authentic telepresence exchanges.

MeetinVR - A VR application optimized for teamwork and collaboration.

AltspaceVR - A VR application for events, shows, and meetups.

ITI VR Crane Simulator by **Serious Labs** - an industry leading training simulator for crane operators.

VirtualSpeech - A platform focused on providing VR soft-skills courses and simulations.

Strivr - A company providing custom immersive learning services across a variety of industries including retail, logistics, manufacturing, and financial services.

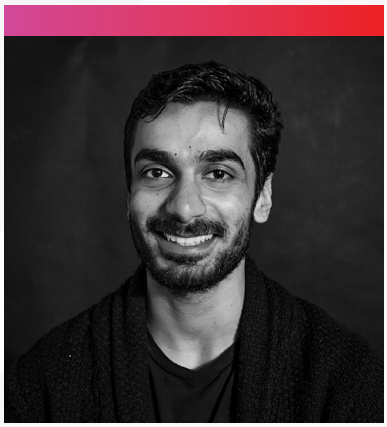
EDGE - (Enhanced Dynamic Geo-Social Environment)- a free VR training platform for first responders and education institutions.

Skylight AR by **Upskill** - A custom enterprise applications for smart glasses, phones, tablets, and AR devices

Scope AR - A AR knowledge platform for work instruction and remote assistance.

Talespin - A spatial computing platform for talent development.

Author Bio



ARCHIT KAUSHIK is a creative technologist and experience designer based in Brooklyn, New York. He blends his technical background and design expertise to examine our evolving relationship with technology and its impact on individuals, communities, and systems. He teaches various aspects of new-media design, including VR development, game design, and creative coding at Parsons School of Design. Currently, he is a XR for Change fellow at G4C, where he is creating and curating experiences that familiarize people with the XR landscape. Archit believes that making is a form of research and that play and experimentation are crucial to how we understand and interact with new technologies. In his spare time, he can be found singing to his houseplants.