Future Care Capital

White Paper

The Potential of Extended Reality (XR) in Healthcare Education

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We would like to thank all those who engaged with us during the writing of this paper.

We welcome feedback and if you want to collaborate with us, please get in contact. All our details can be found at the rear of this report.

About FCC

Future Care Capital (FCC) is an ambitious, visionary organisation focused on facilitating and leading the beneficial transformation of health and care provision. Beginning life as the National Nursery Examination Board (NNEB) in 1945, the charity has evolved throughout its near 80-year history.

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Executive summary

Extended reality (XR) offers significant potential to improve both the access to healthcare professional training and ongoing development and the effectiveness with which it is delivered. In so doing, XR could enable more people to provide better care, more readily. With this, the burden placed on the healthcare system and those working in it might be lessened and critically, the experience of those receiving care and their outcomes improved.

Immersive technologies have gained traction in recent years as technology has advanced and the need for change intensified in the face of the Covid-19 pandemic. The requirements of medical education are evolving too, not least in an environment where opportunities for practical clinical experiences are becoming more limited. **In response, the application of XR educational technologies offers potential for greater learning and development, generating capacity and additional capability of those providing care as well as workplace satisfaction.** Applied at scale, the return for all could be even greater, **not least for those in receipt.**

For this to be realised, it is essential that the barriers to the adoption are addressed. This report outlines the potential offered as well as these barriers and provides three key recommendations for successful implementation of XR at scale in medical education:

- **As XR technologies continue to evolve, there is a need for robust contemporary and validated evidence on the use and impact. This evidence will support the scaling of XR in both the healthcare setting and marketplace. Knowledge and evidence should then be shared through Communities of Practice and Centres of Excellence and form part of a clear dissemination strategy.**

- **As a greater number of innovations become available, it is essential that all stakeholders adhere and work within an over-arching framework that ensures governance, standards and regulation.**

- **One of the most considerable barriers for organisations to overcome in XR implementation is demonstrating a clear Return on Investment. In order to address this, a compelling value proposition that engages all stakeholders and considers both costs and benefits must be established.**

Medical education institutions, healthcare organisations and healthcare professionals are no longer overlooking the potential of XR technologies in providing their services. They recognise the need for an integrated process to ensure implementation success, improve patient outcomes, increase workforce capacity and readiness to go to market.

This report presents the potential benefits of how XR can be used in medical education for healthcare professionals, the existing barriers to integration into the healthcare ecosystem and how these maybe overcome.

Introduction

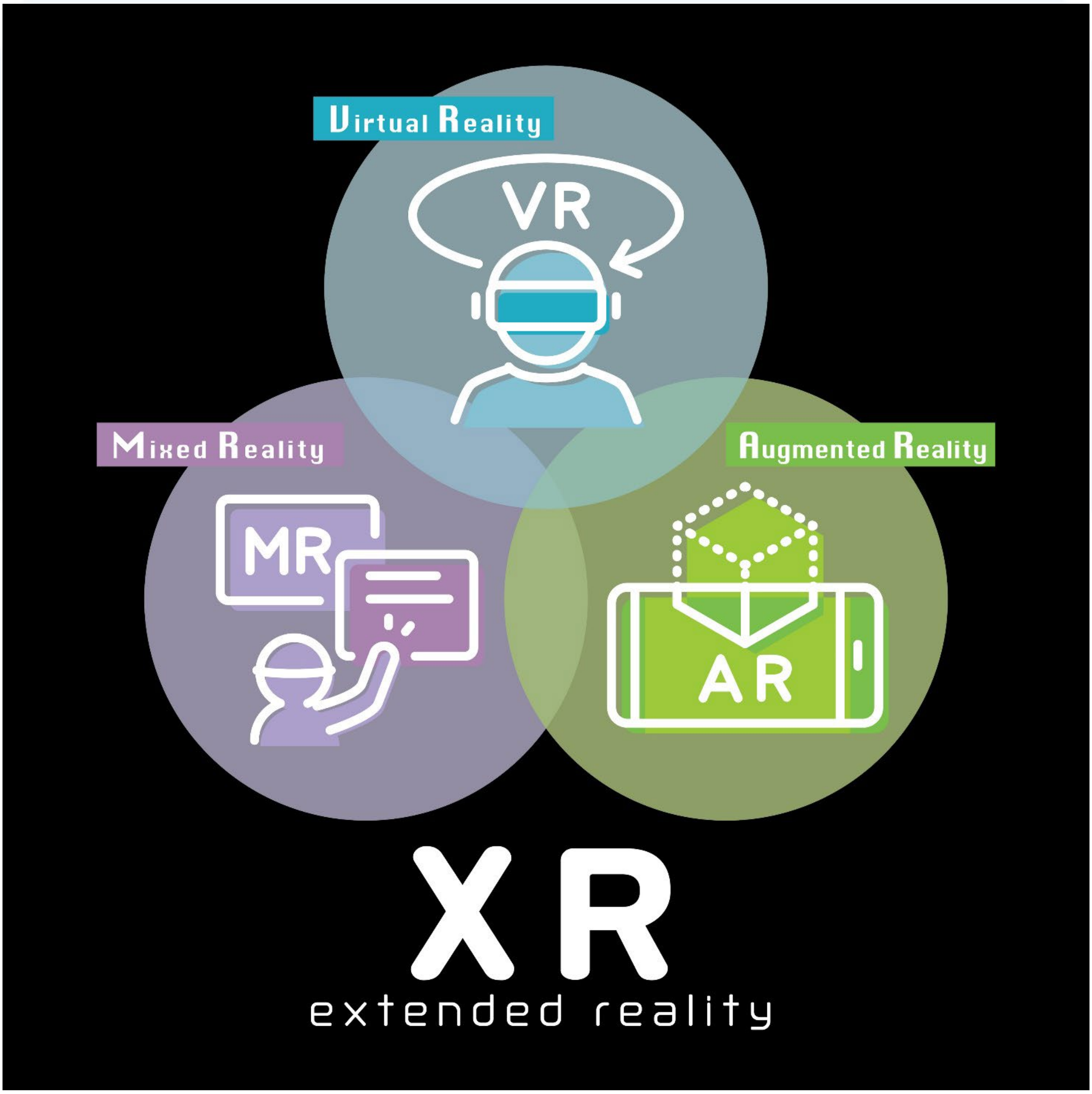
Extended reality (XR) is an umbrella term to define all immersive technologies including virtual reality (VR), augmented reality (AR) and mixed reality (MR). VR is where an individual is totally immersed in a closed virtual environment using a VR head mounted display (HMD) and other wearables for advanced sensory perception [1]. AR is an enhanced version of reality created by using smartphones or smart glasses to overlay digital information (texts, graphic images, or 3D contents) into the user's direct vision of the real world [2]. For example, Google Glass is an optical HMD that can capture and display audio and video images in real time while interacting with the surrounding environment [3,4]. AR differs from VR in that the AR user has a more realistic impression of reality compared to a closed virtual one, as some of the viewed objects are real and some are virtual. Therefore, the AR user is able to interact with virtual information in the context of their real-world surroundings [3]. MR combines elements of AR and VR, to produce new environments and visualisations, where physical and digital objects co-exist and interact in real time. Users wear an HMD, for example Microsoft HoloLens to create objects like holograms [5]. The ability to enhance interaction between the physical and virtual environments, while preserving a feeling of presence, is transforming healthcare, benefiting patients, healthcare professionals and the overall healthcare system [6].

Immersive technologies have gained traction in recent years as a result of rapid technological advancements and the need for change as a result of the Covid-19 pandemic [7]. Previously, XR technologies were primarily associated with the gaming and entertainment sectors. However, post Covid-19, XR has made significant advancements in a range of fields, including healthcare. Dr Neil Ralph, Head of Technology Enhanced Learning at NHS England (NHSE TEL), stated that "the Covid-19 pandemic has had a significant impact on training and education, some of which was unexpected. These changes include the necessity to adopt new models of learning and teaching and the opportunity to use new technologies which can positively support the NHS" [1]. While the market for XR in healthcare is still in the developing phase, experts forecast by 2030, the XR in healthcare market will be worth over 25 billion U.S. dollars globally, up from around 3 billion U.S. dollars in 2023 [8].

XR has the potential to improve healthcare. The technologies offer a wide range of applications, including accurate symptom detection, rehabilitation and physical therapy, mental health treatments, pain management, surgical training and planning, 3D medical imaging and provision of immersive and interactive medical training to healthcare professionals [1,2]. Phil Moore, Digital Innovation Lead at Insight, said "leveraging our understanding of XR technology, will lead the way in revolutionising healthcare in the UK" [9]. XR technologies provide new immersive and engaging ways to learn complex medical content, improve competencies, enable healthcare professionals to gain practical knowledge and improve their decision-making abilities [10]. This places the emphasis on providing an autonomous, blended learning environment, which is expected from the learners of today [11]. In the United Kingdon in 2023, Imperial College London, launched the innovative online course 'Extended Reality in Healthcare Education and Clinical Practice' which aimed to "help people who are excited about XR make a real impact on medical education and clinical practices" [12]. In the United States, medical institutions, such as Stanford University School of Medicine, have embraced XR technologies to enhance medical education. Virtual reality simulations allow students to practice medical procedures, interact with virtual patients, and develop clinical skills in a safe and controlled environment [13].

Medical education institutions, healthcare organisations and healthcare professionals can no longer ignore XR technologies in providing their services. Professor Ara Darzi at Imperial College London, leads academic and clinical groups that have shown that XR training is transforming the way healthcare students and professionals learn today [14,15].

This aim of this report is to review the use of XR in medical education for healthcare professionals and students both in the UK and internationally, to discuss existing barriers and how they may be overcome.



Use of XR in medical education

With the changing demands in medical education and reduced opportunities for practical clinical experiences, the use of educational technologies offers additional possibilities for training and promoting experiential and collaborative learning [2,16]. With increasing pressures on education and training budgets, XR has created a safer, more suitable, and cost-effective learning experiences through which authentic education and training tasks can be simulated [17,18].

Joe Varrasso, ex Microsoft lead for HoloLens Partner ecosystem in UK and founding member of Holomedicine Association, said "evidence is emerging that XR and AI can play a role in cost effectively meeting demand for high quality training for the healthcare workforce with studies showing better pass rates at frequently under one tenth of the cost of physical simulations" [19].

Immersive XR also has the potential to increase learner engagement, improve spatial representation and bring learning into a context that can make the experience more meaningful to healthcare professionals and students [10].

Rachel Dunscombe, CEO of NHS Digital Academy and Professor at Imperial College Medical School stated "to allow for the development of XR in medical education it is important to change the paradigm and allow for experiential learning by using XR technologies" [20].

Use of XR in simulation

Simulation using XR is increasingly becoming a foundation of clinical training, as it can be used to teach anatomy, be adapted to realistic clinical care situations and to recreate complex healthcare processes by generating an immersive experience [21]. These computer-generated simulations use HMDs, wearables and mobile apps to allow the user to be immersed in an interactive virtual environment. These create situations that replicate real life allowing the user to learn from experience but in the virtual world. Smart glasses are a type of HMD and wearable technology that incorporates a video camera that records what the user is viewing and displays a variety of information [22]. Google Glass is an example of an optical HMD that can capture and display audio and video images in real time while allowing the user to interact with the surrounding environment [3]. One of the latest and most advanced implementations of Smart Glasses is Microsoft's HoloLens, that has the capacity to overlay stereoscopic 3D graphics of a hologram on top of the real word, which presents as a three-dimensional model reconstructed in real time [22]. Amanda Baugh, Head of Innovation at Birmingham Women's and Childrens NHS FT stated that "there are a range of XR technologies and equipment that exist and can be applied to a number of scenarios that widen users' learning" [24].

Practical implementation and curriculum integration vary depending on the XR platform and institutional need. For example, in the UK, Cambridge University Hospitals (CUH) and the University of Cambridge Faculty of Education have formed a collaboration with GigXR, where trainees including medical students, nurses and doctors seeking to enhance their clinical skills, will be able to use holographic patients to practice high-level, real-time decision-making and treatment choice. Dr Arun Gupta, CUH consultant and Director of Postgraduate Education, Cambridge University Health Partners, said "simulating real-world, real-time medical care requires interactive, responsive patients, training tools and evolving scenarios that conventional methods cannot accurately recreate. We hope to kick off a new era of simulation that facilitates the seamless exchange of global medical knowledge, which transforms theoretical insights into true-to-life practice" [25]. As well as hospitals and universities, VR platforms are also being used across healthcare systems, with Health Education England, East of England supporting delivery of VR simulation across 18 NHS trusts since August 2019 [11]. In the United States, XR allows medical students at UC San Francisco, to repeatedly practice techniques in life-like virtual environments, by using holograms to practice dynamically removing layers of tissue and organ systems at no risk to patients. Relative to traditional cadaver-based training models, virtual environments simulate the movements and reactions of living patients, ultimately mitigating error and promoting superior health outcomes [26].

Data shows that the use of VR simulations in medical education is didactically effective because it increases the knowledge and academic performance of students when compared with traditional teaching methodologies, online and face-to-face [27]. Studies in healthcare support the value of VR. For example, medical students demonstrate significantly higher knowledge gain when using an immersive environment rather than screen-based learning [28].

XR platforms are commercially available, can be integrated into existing IT systems and be designed for ease and safety of use. Simulations can be used as part of whole teaching sessions, independent learning and for assessment and evaluation purposes. This flexibility allows the integration of simulation based education into everyday practice where it can become a regular occurrence, alongside other learning activities and clinical commitments. As XR scenarios are repeatable, it allows users to practice safely to improve performance and skills, which is noted as one of the key features to successful simulation. This opportunity for self-directed learning will equip learners with the necessary skills for life-long learning, which is fundamental to their medical training and career progression. Research has shown that, the gamification aspects of XR simulations fosters learner engagement, autonomous learning and an enjoyable learning experience [29,30].

A study by Ditzel and Collins (2021) evaluated the student experience of using the Microsoft HoloLens (HMDs) and the HoloPatient application (app) to perform a nursing assessment of Jerry, a life-sized hologram of a man admitted to an emergency department. The findings from this study support previous data that HoloLens technology offered an immersive and engrossing learning activity for students. It further suggests that XR technologies may fast-track learning, decrease practice time and improve learning outcomes for healthcare students [31]. Minty et al, 2022 concluded that using MR (HoloLens) in Objective Structured Clinical Examinations (OSCEs) of medical students is comparable to traditional in-person examination and therefore is a valid and robust method for objectively assessing performance [32]. A study at the University of South Carolina Medical School, used a cardiopulmonary patient simulator called Harvey to train cardiac examination skills. They found that using the XR simulator, students performed better than those trained on physical patient models [33].

Simulation can also be used in the training for emergencies and high risk scenarios. A study by Otero-Varela in 2023, reviewed and evaluated the effectiveness of XR training methods for medical first responders in mass casualty incidents and concluded that XR allows participants to develop high-quality skills in realistic and immersive environments and that XR simulation has become a promising tool for emergency medicine [34]. In the Netherlands, Schola Medica has introduced a VR emergency care education system (THRIVE), which uses VR to engage healthcare professionals with realistic scenarios that ensure that they follow the correct steps in an emergency. This contributes to the learners medical professionalism and their self-confidence in real-case scenarios [35].

Healthcare professionals are trained to work in a range of healthcare settings, therefore it is fundamental that their medical training also includes learning about social interactions and human behaviours (soft skills). XR technologies can be used to develop and improve their skills to prepare for routine, emotive and complex social situations in a controlled and managed environment. Health Education England in partnership with Fracture Reality, created 'a groundbreaking patient avatar that allows healthcare users to expand their skills interacting with people with perinatal mental health problems via a series of instructor-driven simulations.' In doing so, England became the first country in the world to launch clinical training in perinatal mental health using XR technology [36]. The Centre for Immersive Technologies at the University of Leeds evaluated this training experience and concluded that this new immersive method of training is highly usable and useful for students and educators. Some highlights include participants showing significant improvements in cognitive and emotional understanding after using the simulation [37]. Dr Faisal Mushtaq, Director of the Centre for Immersive Technologies, said "the enormous potential for XR to accelerate learning has been clear for some time. But thus far, most examples in healthcare have been limited to areas involving 'technical skills'. This project is significant because it demonstrates how these technologies can help people deal with difficult emotionally challenging conversations that can arise in mental health consultations. This is a big step forward for using XR to support learning and skill acquisition" [38].

XR further supports the development of inter-professional communication skills within the workplace [39]. Research suggests that the implementation of XR simulations and multidisciplinary scenarios, based on real clinical practices, enables the training of students and the further education and training of healthcare professionals [31,40]. As an educational resource, simulation scenarios should be objective, standardised and be part of competency based knowledge and skills training. Users have the opportunity to practice and develop skills prior to seeing patients. In creating a bespoke simulation package, organisations can ensure consistent quality, adherence to protocols and establish an assessment and evaluation framework. All performance data generated is valuable for ensuring compliance, encouraging user engagement and for identifying users who may benefit from further training.

XR technologies can be a useful resource in the delivery of excellent quality of care to patients and to help healthcare organisations grow workforce capacity. David King Lassman, Founder of GigXR commented that "the healthcare personnel shortfall is dire around the world with projected shortcomings of hundreds of thousands of personnel in countries like the US and UK. Further exacerbating this problem are the

compounding factors of healthcare professionals leaving the workforce (catalysed by COVID burnout) and the inability to train people fast enough to not only replace those leaving but to fill the shortfall caused by an ageing population" [41]. His view is that the key to solve this issue, is to train more people faster, which requires the use of new technologies like XR. It is important for healthcare to follow the models as set out in other industries to reduce this trend and increase workforce capacity. For the existing workforce, XR can also be seen as a motivational and support tool for practitioners in raising skills, supporting their learning and development and increasing enjoyment and satisfaction in their job role. John Bryant, Director of Integrated Care and Generative Relationships at Devon Innovation, led a trial on the use of AR in practice, in a bid to cut demand and stress on the NHS. He said "often people are looking for a silver bullet for 'substitutional' technology, replacing humans with tech when there's a resourcing shortfall. What we're doing is looking at technology and asking how it can enable people to perform better, enjoy their work more and provide even better outcomes for patients, clients and staff" [42]. Providing innovative immersive learnings experiences can be a motivating factor in the recruitment and retention of staff, thereby further increasing workforce capacity.

Use of XR for telesimulation and telementoring

Telesimulation is an emerging field with potential for expanded use in healthcare education [40]. It is a process by which telecommunication and immersive technologies such as HMDs are used to provide education and training to learners at remote locations [43,44]. Learners can interact with each other, simulated patients, visual displays and facilitators in real-time to acquire skills and receive remote supervision and assessment [45].

Telesimulation in skills and performance training has been used in many areas of healthcare, for example laparoscopic surgery, robotic surgery, ophthalmologic surgery, and ultrasound [46,47,48]. Telesimulation has also been used to educate healthcare professionals in regions of the world with limited resources and where they do not have access to costly simulation setups and trained teachers and instructors. Within the hospital setting, telesimulation can also be used for instruction in critical care disciplines, for example paediatric resuscitation, surgery and emergency medicine [47,49]. Telesimulation can also be used for debriefing healthcare professionals at remote locations and can be accomplished in an easy and cost-effective manner using basic equipment [50].

In rare and high risk scenarios, telesimulation has been shown to be effective in providing critical training, supervision and assessment [51]. A military study which aimed to assess the efficacy and feasibility of training of isolated emergency healthcare personnel, concluded that patient simulation through the use of telesimulation improved perceived preparedness and self-efficacy in emergency healthcare staff. Telesimulation and distance education provides isolated medical personnel the opportunity to practice skills without being limited by distance and location [52].

Telementoring is another form of enhancing medical education remotely. It uses XR and HMDs to establish a relationship in which an expert provides guidance to a less experienced learner and can also be used for remote consultation among colleagues [45]. Smart Glasses can also live broadcast, connecting medical personnel outside the surgical field for hands-free telemonitoring during surgery and for reviewing patients' medical records and images [3,45]. This technology provides a practical and cost-effective alternative mentoring tool that overcomes the cost of on-site mentoring programmes that require travel costs and time away from clinical duties. Rojas-Munoz et al (2020) discussed the benefits of using AR-based telementoring (STAR) in the training and instructing of surgical professionals in rural areas. They concluded that in using AR-telemonitoring, learners made fewer errors and received better performance scores and had increased confidence in these skills as a result of this application [53].

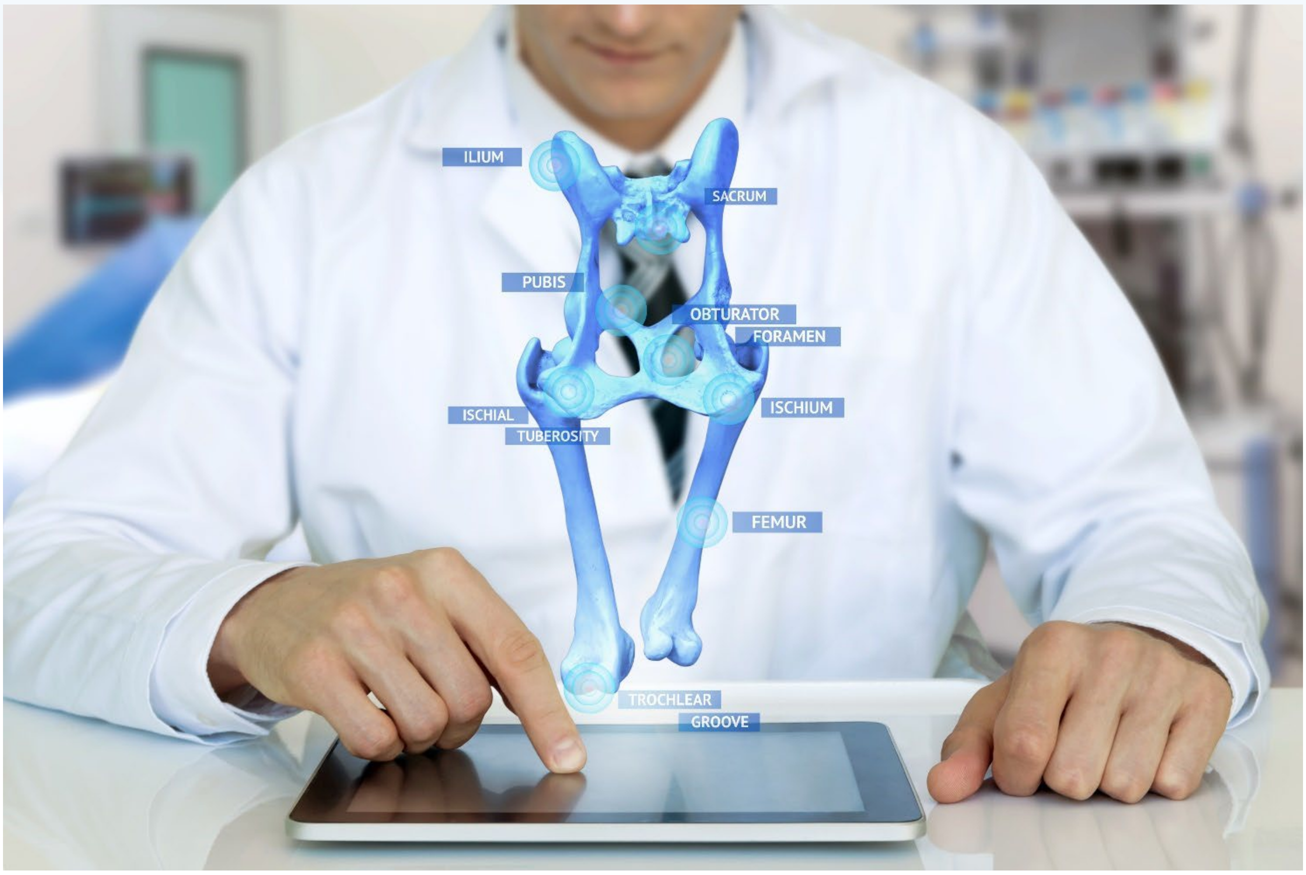
Use of XR in anatomical education

Anatomy has traditionally been taught via human cadaveric dissection, lectures and written materials for healthcare students and professionals [54,55,56]. Although cadavers remain the established model for teaching anatomy, there are significant financial, ethical and supervisory limitations on their use. Some universities have also reduced the number of hours allocated to teaching of anatomy in this way [18]. Subsequently, students may need to use supplementary materials to enhance their anatomical knowledge through self-directed study [57].

XR technologies provide innovative ways for anatomical education as it allows students to explore three-dimensional views of the human body without the limitations of cadaveric teaching [58]. AR magnifies the learning process, as it can create or simulate anatomy and certain conditions that help students practice with virtual objects that resemble the human body and organs. It provides real-life experiences that have low risks, are affordable and provide effective training. This allows real time data and performance feedback, to improve education in the required skills and knowledge. In papers by Kurul et al (2020) and Weeks et al (2020) both concluded that VR and AR led to substantial anatomy knowledge improvement compared with conventional training methods [59,60]. Moro et al. (2017) indicated that VR, AR, and smart devices were equally effective in anatomy teaching, but VR and AR showed greater benefits, such as enhanced student engagement [18].

XR technologies using holograms, such as Microsoft HoloLens are now considered an important part of healthcare professionals' education [17,51,43]. They can be used to teach human anatomy, presenting three-dimensional structures in the immediate learner environment. It provides a hands-free experience and allows users to manipulate holographic images in real space and time [61,55]. It transforms how anatomy content is visualized and offers a realistic and cost-effective solutions to the many challenges of cadaver-based dissection [62]. The University of Central Florida College of Nursing implemented AR and VR for anatomical education for nurses and nurse practitioners. Mindi Anderson, Interim Associate Dean for Simulation and Immersive Learning and director of the school's healthcare simulation graduate program stated one of the benefits of using AR and VR comes from viewing the anatomy of the human body. "There are scenarios where the student can walk inside the body and see what's happening behind the scenes with that pathophysiology, anatomy and physiology, so they can really get that understanding of what is happening with the patient. This can help with interventions" [63].

An important aspect of anatomical education is an understanding of how anatomy relates to function. AR has been shown to assist learners, as they can add and/or remove different anatomical structures from the hologram. XR platforms can also include functional features where specific muscles can be flexed, to observe the resulting movement [64]. Learners found this helpful to gain an understanding of complex systems involving multiple muscle groups. Additionally, pathologies and anatomical variations can be added to virtual holograms for in-depth understanding [65]. A study by Zafar and Zachar (2020) investigated dental students perception of AR use for teaching head and neck anatomy. They concluded that AR offers an additional modality of dental anatomy teaching and training and has the potential to be used as an adjunct tool in as it has demonstrated increased student engagement and enjoyment [66]. Adesante, a Finnish company has developed SurgeryVision, which allows users to view MRI AND CT scans in a stereoscopic 3D format, helping them to study anatomy and anatomic abnormalities more effectively [67].



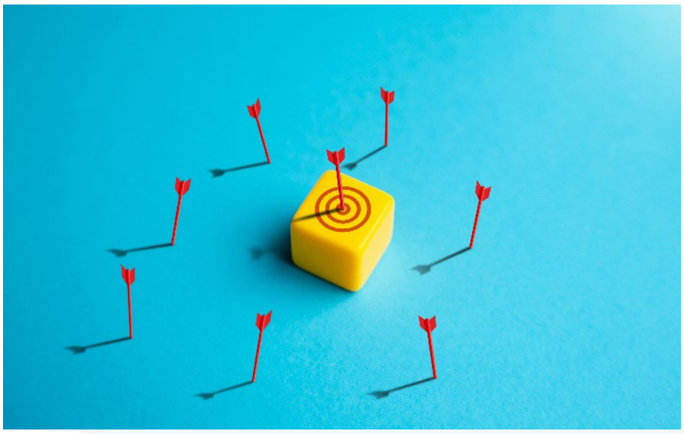
Use of XR in surgical education

In the past, surgeons used traditional methods such as cadavers, observation and hands-on experience in operating theatres to learn and practice surgical procedures. Due to surgeons' increasing clinical and surgical duties, time and experience in the operating theatre can be limited. Dr. Kartik Logishetty, an orthopaedic surgeon at Imperial College London, stated that "modern surgical training is a challenge as there are working time restrictions and fewer opportunities to learn on patients in real life" [68]. Due to the concerns of patient safety, workforce capacity and the knowledge and skills required for complex surgical procedures, surgical education and training is another area where XR technology is being utilised [69,70]. It provides immersive and effective solutions for medical professionals as surgery simulation offers a safe and realistic opportunity for professionals to experiment, train and collaborate. Studies show that XR technologies significantly increase the quality of surgical performance in the operating room, especially in sensitive surgeries such as glaucoma and brain surgery [71,72]. Dr. Kartik Logishetty also stated that "virtual reality training demonstrates that a lot of the learning curve can be moved outside of the operating theatre altogether, so surgeons are prepared for surgery with their cognitive and motor skills, as well as their nontechnical skills even before they get there" [68].

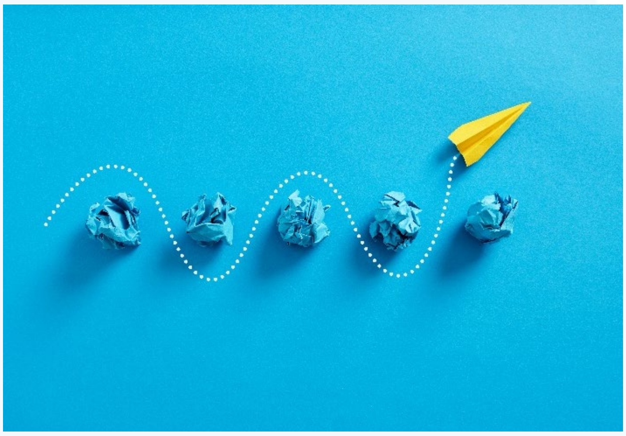
Modern surgery is enhanced by digital technologies which aim to improve the safety and effectiveness of procedures. These technologies include patient-specific 3D planning, simulation training, navigated and robotic tools, remote assistance, and the use of holograms in the surgical environment [73,74]. For example, using 3D reconstructions of CT and MRI scans, surgeons can use XR to perform pre-operative planning more effectively. It gives them a better understanding of a patient's anatomy and surgical area, improves patient positioning for the procedure and develops a detailed surgical plan to perform the operation [73,74]. MR can be used to augment the surgeon's vision by overlaying reconstructed models of a patient's anatomy and the planned trajectories over the surgical field, resulting in increased efficiency and precision. This form of AR surgery on live patients was first performed by surgeons at Johns Hopkins Hospital. During the first procedure, surgeons used AR technology to assist them in placing screws in a patient's spine for spinal fusion. In the second procedure, surgeons again used AR to remove a cancerous tumour (chordoma) from the spine of a patient. The doctors report that both AR-assisted surgeries were completed successfully and both patients were doing well [75]. For especially challenging operations, surgeons can participate in AR-telementoring. Here, a real-time view of the surgical field can be shared with a remote colleague, eliminating the need for peers to be on site [76].

The potential of using XR technologies in surgical education has been widely explored to increase surgeons' exposure to procedures given the time pressures of the operating room [77,78,79]. The validity and usability of XR applications has been examined across various surgical specialties. Research by Imperial College London concluded that 83% of VR-trained users could complete a spinal surgery with minimal guidance, whereas 0% of traditionally trained users could accomplish the same task [80]. VR offers experiential surgical education, to help surgeons increase their skill level. A study from UCLA's David Geffen School of Medicine saw a 230% boost in overall performance in tibial intramedullary nailing, a procedure to repair a fractured tibia, among VR-trained surgeons relative to their traditionally trained counterparts [81]. In the field of neurosurgery, a study by Roh et al. (2021) reported that by introducing integrated photographic 3D models into VR for education, surgeons found the technique of XR simulation beneficial in improving their surgical skills and developing new surgical approaches [82]. Mitani et al. (2021) developed MR 3D holograms in otolaryngological tumour resection surgery to view using HMDs. This was reported to be more useful than the radiological images displayed on a computer screen [83]. In orthopaedic surgery, Lohre et al. (2021) examined the validity and efficacy of using immersive VR compared to a traditional learning modality in orthopaedic education. The study showed that immersive VR led to a substantial increase in learning improvement over traditional teaching methods [84]. Nagayo and colleagues developed an XR platform for open surgery training, during the procedure the movement of surgical instruments and patient anatomy was captured and then reconstructed using an AR program. Users were able to manipulate their view as they progressed through the procedure, to direct their learning and practice their surgical skills and their use of surgical equipment [85].

Barriers and how to overcome them



The use of XR technologies in healthcare and medical education is gaining momentum, driven by a number of factors. These include, improving patient outcomes, increasing workforce capacity, saving staff time and improving their experience, increasing accessibility and improving efficiency and cost of services. Jade Ackers, Programme Director for Digital Productivity in the NHS Transformation Directorate recognised the "tremendous potential of immersive simulative solutions and how they can directly reduce the time and improve the vital training and education for healthcare physicians." [86].



However, it is essential that the barriers to the adoption of such technologies are acknowledged if their true capability is to be realised. Fundamentally, the use of these technologies as an educational resource, not only directly affects the knowledge and skills of healthcare professionals who use them but also their impact on patient outcomes and safety.

Usability and accessibility

A number of papers and case studies show the benefits of using XR technology in medical education but they also recognise that such technologies are subject to limitations [87,88,89]. These limitations and barriers must be addressed in order for organisations to make strategic decisions related to the use and implementation of these technologies in healthcare and medical education programmes. Approaching XR technology as a solution for a specific educational use neglects its broader potential. These technologies should be part of a comprehensive, long-term strategy that allows for technological development, user engagement and ongoing organisational requirements.

Within medical education, XR technologies can be used as a tool to accomplish a defined set of learning outcomes and should be positioned as such. They should be integrated within an organisations' knowledge and skills training framework to ensure effective use and adherence to professional standards and competencies. XR technologies are not suitable for every educational opportunity and should not always replace the expert educator. Organisations and educators must decide which objective they are looking to achieve and establish the most appropriate method of delivery. For example, in surgical training it has been reported that XR may not replicate some organic tissues or accurately simulate aspects of medical care and surgical scenarios, thereby creating unrealistic pseudo-environments [90]. In scenario-based XR simulations, holograms are used to represent a real patient. However these holograms do not always fully replicate language and facial expressions and therefore a human is more suitable than a virtual patient [11]. Umang Patel, Chief Clinical Information Officer at Microsoft and paediatric doctor, said “while holograms for simulating conversations could be good, he is not convinced that the kit is good enough yet”. He suggests that further testing and evidence is needed to determine if using hologram patients versus actors simulating patients are more effective [91].

Some evidence indicates that the use of XR technologies does have some negative effects for the user that could be detrimental to overall learner engagement and effectiveness [88]. For example, it has been shown that wearing an HMD can cause motion sickness, cybersickness, variable degrees of eye strain and can also force the wearers to modify their neck posture [92]. Therefore, managing and monitoring the health of users of XR platforms is necessary. McKnight et al (2020) reports that multiple studies have demonstrated that HMDs can cause side effects such as nausea, headaches and vertigo. However, technological advancements have reduced the severity of these effects, allowing users to wear HMDs for longer periods of time and be fully engaged in the learning experience [93].

It is important to make the XR learning experiences attractive and easy to navigate for users, as user engagement and acceptance issues often lead to disengagement with the technology and reluctance to use it. This has subsequent cost implications as the benefits of the financial investment are not fully accrued [94,95]. Of late, when designing XR platforms, organisations and innovators are collaborating with users to create more attractive, usable and engaging platforms [96,97,97]. Issues of accessibility when using XR technologies also need to be considered, including the impact of disabilities, underlying health care conditions that are contraindicated with XR use and socioeconomically disadvantaged users. Organisations must provide alternative educational opportunities and support for the diverse user workforce. XR technologies for education can also mitigate the geographical barriers to training as it affords users the opportunity for autonomous learning without the confines of a determined location. This self-directed learning furthers the potential to reduces issues of accessibility, inequalities in training and have a positive impact on patient safety.

High initial costs for XR technology

Education and training can be a financial burden on organisations and as such more cost-effective and accessible solutions are constantly being sought. The introduction and use of XR technologies in medical education can be costly, due to high initial costs for technology (hardware and software), content creation and training expenses. Research, due diligence and evaluation of XR devices and platforms is essential prior to purchasing. When proposing an XR educational platform, the initial physical costs of hardware and software are budgeted. However, the hidden costs, such as ongoing licencing fees (per-user, per-device, or site-wide licenses) are underestimated or omitted and can have significant impact if overlooked. One of the most considerable barriers to overcome in XR implementation is demonstrating a clear Return on Investment (ROI). Torbay and South Devon NHS Foundation Trust’s Digital Futures programme, showed in a pilot study how staff used MR HMDs for remote consultation for breast wound care to save the trust £40,000 a year compared to traditional delivery of care, therefore, justifying the use of this technology and providing a clear ROI [99]. By articulating a compelling value proposition that considers both costs and benefits, support from stakeholders will be generated and will ensure long-term financial sustainability and implementation success.

Stakeholder engagement and approval

Strong stakeholder approval is crucial for successful XR engagement and implementation. The NHS Digital Productivity Programme, from NHS Transformation Directorate identified that the most common barrier was the lack of quantitative and qualitative evidence on the value of XR [86]. In order to overcome this and gain support from stakeholders, it is essential that data showing value, safety, impact and ROI is presented. Therefore, a collaborative approach between healthcare organisations, industry and research and academic institutions should be encouraged with the aim of using evidence-based practice, case studies, recommendations and evaluation to develop the XR evidence base. The NHS England, Digital productivity fund, Transformation Directorate awarded 14 NHS sites £2 million from the Unified Tech Fund to pilot XR projects and generate evidence and learnings [86].

Another important aspect of stakeholder approval, is changing the mindset of stakeholders, especially patients and clinicians who may be hesitant of change and the culture of innovation. Professor Shafi Ahmed, a cancer surgeon at The Royal London and St Bartholomew's Hospitals, is using XR to live stream operations to educate people on a worldwide scale. He stated that in order to encourage acceptance and approval of XR technologies in medical education, organisations need to "knock down the silos and consider what is missing – the people, the process and the support needed" [100]. Organisations need to work with stakeholders to clearly outline the objectives of using XR technologies, how they are aligned with the organisations aims and objectives and the specific educational uses in order to gain their approval.

Route to market

While user engagement, financial implications and stakeholders acceptance are important factors, organisations must demonstrate that XR technologies provide value and have an educational advantage in order to facilitate successful implementation [101]. Research and development of XR cannot sit in isolation but should foster collaborative working across different industries. The aim of this would be to develop and refine XR innovations suitable for clinical and educational uses. Research shows that there is not a consistent marketplace for the testing, evaluating and dissemination of XR technologies. There are no clear resources for pilot studies and testing to build market ready robust solutions and test at scale [7]. The opportunity to develop innovations into evidenced based solutions is lacking and as a result a quantifiable determination of its value and impact is not available. Also, the opportunity for developers and industry to engage and promote technologies to organisations and commissioners is fragmented. Subsequently, these obstacles prevent a clear 'route to market'.

Communities of practice (CoPs) and 'Centres of Excellence' (CoEs) are proven methods of sharing knowledge and evidence and the dissemination of good practice [102]. The University of Queensland, Australia has adopted this approach and has formed an 'Immersive Reality CoP' in which faculties across different disciplines collaborate to share knowledge and practices for XR across the university [103]. CoEs develop common solutions, promote best practice and acquire new skills that are then spread throughout the enterprise to increase the likelihood of adopting new ways of working to realise value and allow teams to become self-sufficient [104]. For example, the RESILIENCE Centre of Excellence for UK Medicines Manufacturing Skills (run by an academic consortium of UK universities led by the University of Birmingham alongside UCL, Teesside University, and Heriot-Watt University as well as Britest LTD) received funding to deliver training. This will include the use of VR and MR situations, providing students with 'near to real life' experiences of lab environments for medicine manufacturing. Professor Vikki Rand, Director of Teesside University's National Horizons Centre, a national centre of excellence for bioscience and healthcare, said "by combining hands-on training on the latest equipment with digital technology, including VR and AR, we deliver real impact for the companies, by saving quality time and resources and giving them the ability to train their employees at scale" [105]. In XR, CoPs and CoEs should be used to create a defined development framework which enables a clear pathway from conception, R&D, development of the evidence base, investment and scaling to market. Dr Neil Ralph, Head of Technology Enhanced Learning, at HEE, has discussed this issue and said with the NHS "we are working on a dynamic approach to procurement to support a clearer route to market, to capture the best solutions and services across the XR and immersive technology sector" [38].

One potential framework to address these barriers to adoption is a 'go-to-market strategy,' similar to that used in the business and startup world. A go-to-market strategy is a comprehensive plan that can be used bring a new product or service to market. It is designed to mitigate the risks inherent in the introduction of a new product or service and identifies and provides value to a specific user group [106]. Innovation in medical education poses a number of challenges, such as stakeholder adoption and advocacy by educators who have a more traditional approach to medical education and training [18]. In order to overcome this, engagement is essential and educators should be involved in all phases, from the development, identification of learning objectives, system design, implementation, to the validation and integration of XR technologies into education and training [2]. Mark Sutton and Fred Tovey-Ansell at the School of Engineering at Imperial College London, expressed the view "that it is a people problem, not a tech problem. Subject matter experts and educators must be involved from the start, to ensure quality and identification of the benefit of each XR technology" [107,108]. A multidisciplinary approach between these educators and innovators, students and users to test and pilot the use of XR is advised [2].

Governance and regulatory requirements

Clinical governance may be defined as 'the framework through which healthcare organisations are accountable for continuously improving the quality of their services and safeguarding high quality of care' [109]. The healthcare industry and its regulators have strict compliance standards when it comes to healthcare privacy and the security of patient and staff information. XR devices generate a vast quantity of highly personal data that is unique to XR and this information must be safeguarded. This form of data also presents ethical challenges, particularly when patient and user information and consent is required. Working through these ethical frameworks, can be a lengthy process as there are multiple stages and approvals to be met.

There are a numerous standards, quality frameworks and regulatory guidelines across NHS Digital, DTAC, MRHA, and NICE. As such, current regulatory definitions of personal information and data may not be sufficient to provide this level of security. Regulators must collaborate with industry, healthcare and academic organisations to incorporate the use of XR device classification, cybersecurity and data protection into current medical device regulation and governance frameworks. In order to alleviate the complexity and time required to work through the range of compliance and quality assurance frameworks, standards should be defined and incorporated into an overarching regulatory policy to produce a set of practical controls and guidelines. This will enable faster deployment of XR training and education technologies in the marketplace which can be implemented in academic and clinical practice.

Conclusion

XR has the potential to improve healthcare and is at the forefront of new and exciting innovations and technologies. These technologies offer a wide range of applications, including accurate symptom detection, rehabilitation and physical therapy, mental health treatments, pain management, surgical training and planning, 3D medical imaging and provision of immersive and interactive medical training to healthcare professionals [1,2,110]. **The immersive and interactive nature of XR experiences provides a safe and controlled environment for medical professionals to learn complex medical content, improve competencies, gain practical knowledge and improve their decision-making abilities.**

The accessibility and cost-effectiveness improvements of using XR technologies in medical education have facilitated its growth and adoption within the medical education sector. It is anticipated that as XR technologies continue to evolve, the evidence base and sharing of knowledge will further develop and advancements will be made that can support scaling of XR in the healthcare setting. As a greater number of innovations are available in the marketplace, it is essential that all stakeholders adhere and work within an over-arching framework that ensures governance, high standards and regulation.

This report has presented the potential benefits and case studies (both nationally and internationally) of how XR is used in medical education for healthcare professionals, the existing barriers to integration into the healthcare ecosystem and how these barriers maybe overcome. Medical education institutions, healthcare organisations and healthcare professionals are no longer overlooking the potential of XR technologies in providing their services and recognise the need for an integrated process to ensure implementation success at scale and readiness to go to market.

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