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Exploring the Role of Immersive Technology in Medical Education

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The thesis is submitted in fulfilment of the requirement for the degree of Doctor of Medicine in the School of Medicine, Obstetrics & Gynaecology, University College Dublin

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Research undertaken at:
UCD Perinatal Research Centre, The National Maternity Hospital Dublin, Ireland

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Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
3D-US	Three-Dimensional Ultrasound
3DVT	Three-Dimensional Visualisation Technology
3DVWs	Three Dimensional Virtual Worlds
ACER	Average Cost Effectiveness Ratio
AECT	Association for Educational Communications and Technology
AI	Artificial Intelligence
AMEE	Association for Medical Education in Europe
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AR	Augmented Reality
ASME	Association for the Study of Medical Education
BEME	Best Evidence Medical Education
BIO	Binocular Indirect Ophthalmoscopy
BOOM	Binocular Omni Orientation Monitor
BSc	Bachelor of Science
CAVE	Cave Automatic Virtual Environment
CanMEDS	Canadian Medical Education Directives for Specialists
CDH	Congenital Diaphragmatic Hernia
CFAT	Carnegie Foundation for Advancement of Teaching
CGT- trader	3D Marketplace
CHEERS	Consolidated Health Economic Evaluation Reporting Standards
CSF	Cerebro-spinal fluid
CSTAR	Centre for Support and Training in Analysis and Research
CTML	Cognitive Theory of Multimedia Learning
DICOM	Digital Imaging and Communications in Medicine
FETO	Fetoscope endotracheal occlusion
FMcA	Professor Fionnuala McAuliffe
GR	Grace Ryan
HIQA	Health Information and Quality Authority in Ireland

HMD	Head Mounted Display
HMDs	Head Mounted Displays
HSD	Honestly Significant Difference
HTC	HTC Corporation
IBM	International Business Machines
IDC	International Data Corporation
IEEE	Institute of Electrical and Electronic Engineers organisation
iLRN	Immersive Learning Research Network
ISRCTN	International Standard Randomised Controlled Trial Number
I-VR	Immersive Virtual Reality
LCD	Liquid Crystal Display
MCQs	Multiple Choice Question Tests
MDT	Multidisciplinary Team
MDT	Multidisciplinary Team
MERSQI	Medical Education Research Study Quality Instrument
MESH	Medical Subject Headings
MR	Mixed Reality
MRI	Magnetic Resonance Imaging
NASA	National Aeronautics and Space Administration
NCARDRS	National Congenital Anomaly and Rare Disease Registration Service
OSCE	Objective Structured Clinical Examinations
OSCE	Objective Structured Clinical Assessment
PC	Personal Computer
PDF	Portable Document Format
PICO	Population-Intervention-Comparator-Outcome
PPH	Post-Partum Haemorrhage
PRISMA-P	Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols
QASE	Quality-Adjusted Students Educated
QQ	Quantile Quantile
QR	Quick Response
RCOG	Royal College of Obstetrics and Gynaecology
RCTs	Randomised Controlled Trials

SBAs	Single Best Answer
SCLS	Self-Confidence in Learning Scale
SD	Standard Deviation
SDS	Simulation Design Scale
SL	Second Life
SPSS	Statistical Package for Social Sciences
STL	Standard Triangle Language
TEL	Technology Enhanced Learning
UCD	University College Dublin
USA	United States of America
USAF	United States Air Force
VCRs	Video Cassette Recorders
VPs	Virtual Patients
VR	Virtual Reality
VRDS	Virtual Reality Design Scale
VRLE	Virtual Reality Learning Environment

Ethical Approval Associated with this Thesis

1. Development of 3D images of pregnancy for use in Virtual and Augmented Reality was approved by the Research Ethics Committee, The National Maternity Hospital (Ethics Reference Number EC23.2019).

2. The randomised control trial and midwifery cohort study were approved by the Human Research Ethics committee, University College Dublin (Ethics Reference Number LS-20-09-McAuliffe: To investigate the role of virtual, augmented and mixed reality in medical education 21-05-20).
    a. Virtual Reality Learning: A randomised control trial assessing medical student knowledge of fetal development
    b. Virtual Reality in Midwifery Education: A mixed methods study to assess learning and understanding

3. Virtual reality for patient education: A case series was approved by the Ethics Committee at the National Maternity Hospital (Ethics Reference Number EC04.2020).
    a. To investigate the role of virtual and augmented reality in antenatal patient education

Abstract

Virtual, augmented, and mixed reality are immersive technologies which are becoming increasingly popular learning tools for use in healthcare student education. Research has shown that virtual reality (VR), a form of immersive technology can improve knowledge and the learning experience by applying a conceptual framework to guide lesson plans informed by constructivist and experiential learning theories. VR learning tools could revolutionise the way we deliver and support education. This thesis focuses on VR, which is thought to enhance the learning process by creating an environment by which the learner can develop creativity, learn by doing and increase understanding of complex concepts by providing 3D visualisation. Research is demonstrating that VR can improve knowledge acquisition, however there is a paucity of evidence on whether VR improves the learning experience and how costly the learning tool is and associated side-effects. Therefore, this thesis aims to explore the role of VR regarding the learning experience coupled with the feasibility of the tool in healthcare student education.

This thesis explores the role of VR in medical, midwifery and nursing education. Firstly, the thesis introduces the concept of educational technology as learning tools and the learning theories that guide conceptual frameworks in medical education in a comprehensive literature review. Next a systematic review of immersive technologies in medical, midwifery and nursing education is presented that finds immersive technologies when compared to traditional learning tools are equal in knowledge gain and provide an enhanced learning experience. Furthermore, it also highlights the heterogeneity of instruments used to assess the learning experience. These findings allowed us to design and develop our own virtual reality learning environment (VRLE) on the topic of "*Stages of fetal development in pregnancy*". A conceptual framework

based on experiential learning and constructivism guided the lesson plan and learning objectives. To test the VRLE, a randomised control trial is performed with medical students to assess the effectiveness of the VRLE compared to a traditional didactic tutorial. Validated standardised tools used for simulation based medical education tools are adapted for a VRLE and proposed to evaluate the learning experience with VR educational tools. The VRLE results in equal knowledge gain and offers a positive learning experience despite participants experiencing side-effects. To further assess the efficacy of the VRLE, a second lesson in VR on the topic of "*Fetal lie, position and presentation in the third trimester of pregnancy*" is developed for midwifery students in a mixed methods study. Similarly to the RCT the study findings show that the VRLE had no impact on knowledge gain and participants report a positive learning experience despite a high incidence of side effects. Following this a cost analysis of the VRLE is conducted to assess the cost of VR as an educational tool, study findings reveal that VR is more costly when compared to traditional learning tools. Finally, the development of 3D models of congenital abnormalities for antenatal patient education is described and a pilot case study is presented that shows the potential of VRLEs in this area.

Emerging research suggests that VR technology is thought to be a useful learning tool that can support learning in various fields of medical education by creating an immersive, engaging, and safe learning environment. Although there are challenges facing the implementation and acceptance of VR technology, the advancement and widespread availability of VR technology could negate these challenges. This thesis supports the current literature and demonstrates that VR technology is a novel learning tool that can facilitate learning and a positive learning experience that increases students' self-confidence and satisfaction with learning in healthcare education.

Statement of Original Authorship

I hereby certify that the submitted work is my own work, was completed while registered as a candidate for the degree stated on the Title Page, and I have not obtained a degree elsewhere on the basis of the research presented in this submitted work.

Regarding the systematic review Shauna Callaghan, Research Midwife was involved in the screening of titles and abstracts and analysis of the results. Dr Grace Ryan was involved in all aspects of the systematic review.

Dr Tony Rafferty was involved in the data analysis of the randomised control trial and midwifery cohort study.

Dr Grace Ryan was involved with the development of “VR Baby” as a subject matter specialist and provided input into the design of the VR lesson in collaboration with UCD School of Science.

Dr Grace Ryan was involved in all aspects of the randomised control trial, the midwifery mixed methods study, the cost analysis and patient case series.

Candidate name: Dr Grace Ryan Candidate ID: 19206814

Signed:

Collaboration

The development of the VRLE, “VR Baby” was in collaboration with the School of Computer Science. Under the guidance of Prof Eleni Mangina, John Murphy, a final year Computer Science student contributed to the technical development of “VR Baby”. This involved translating the DICOM images for use within a 3D platform and the development of the 3D platform for the VR Lesson and its transfer onto the headset with specialised hardware and equipment. Dr. Grace Ryan was involved in all steps of the design and development process in conjunction with John Murphy.

Presentations and publications associated with this thesis

Papers Published

1. **Learning outcomes of immersive technologies in healthcare student education: A systematic review of the literature**

   G Ryan, S Callaghan, AR Rafferty, M Higgins, E Mangina, F McAuliffe.

   J Med Internet Res. 2022 Feb; 24(2): e30082. Published online 2022 Feb 1. doi: 10.2196/30082

2. **Virtual Reality in Midwifery Education: A Mixed methods study to assess learning and understanding**

   G Ryan, S Callaghan, AR Rafferty, J Murphy, M Higgins, T Barry, E Mangina, L Carroll, F McAuliffe

   Nurse Educ Today. 2022 Sep 21;119:105573. Doi: 10.1016/j.nedt.2022.105573

3. **Virtual Reality Learning: A randomised controlled trial assessing medical student knowledge of fetal development**

   G Ryan, AR Rafferty, J Murphy, M Higgins, E Mangina, F McAuliffe

   Int J Gynaecol Obstet. 2023 Mar 8. doi: 10.1002/ijgo.14684

4. **A randomized control trial of a virtual reality learning environment in obstetric medical student teaching**

   D. Kane, G. Ryan, E. Mangina, F.M. McAuliffe
   Int J Med Inform.2022 Dec. doi: 10.1016/j.ijmedinf.2022.104899

Papers submitted for publication

1. **A Cost Analysis of a Virtual Reality Learning Environment Versus a Traditional Tutorial to Teach Medical Students about Fetal Development for Obstetrics and Gynaecology Education**

   G Ryan, J O'Mahony, M Higgins, E Mangina, F McAuliffe

   Manuscript under review with **Medical Teacher**

International Abstract publications

BJOG Journal (World Congress Edition) June 2021

1. **" Virtual Reality Learning: A Method to Improve Student Knowledge of Fetal Development- A Randomised Control Trial"**

   G Ryan, AR Rafferty, J Murphy, M Higgins, E Mangina, F McAuliffe.

   UCD Perinatal Research Centre, University College Dublin, The National Maternity Hospital.

   BJOG-AN INTERNATIONAL JOURNAL OF OBSTETRICS AND GYNAECOLOGY, Volume 128, pp.257-257.

   https://obgyn.onlinelibrary.wiley.com/doi/pdf/10.1111/1471-0528.21_16715

6th International Conference of the Immersive Learning Research Network (iLRN), Institute of Electrical and Electronics Engineers 2020

2. **Work-in-Progress—Development of a Virtual Reality Learning Environment: "VR Baby".**

   G. Ryan, J. Murphy, M. Higgins, F. McAuliffe, E. Mangina

   2020 6th International Conference of the Immersive Learning Research Network (iLRN), 2020, pp. 312-315,

   doi: 10.23919/iLRN47897.2020.9155203.

Oral Presentations

RCOG World Congress June 2021

1. **Virtual Reality Learning: A Method to Improve Student Knowledge of Fetal development- A Randomised Control Trial**

   Ryan G, Rafferty A, Murphy J, Higgins F, Mangina E, McAuliffe FM

Blair Bell Annual Academic Meeting RCOG February 2021

2. **Virtual Reality Learning: A Method to Improve Student Knowledge of Fetal development- A Randomised Control Trial"**

   Ryan G, Rafferty A, Murphy J, Higgins F, Mangina E, McAuliffe FM

JOGS RCPI November 2020

3. **“VR BABY”, A virtual reality learning environment- does it enhance the understanding and learning of invisible concepts? A randomised control trial**

   Ryan G, Rafferty A, Murphy J, Higgins F, Mangina E, McAuliffe FM

INHED February 2021

4. **“VR BABY”, A virtual reality learning environment- does it enhance the understanding and learning of invisible concepts? A randomised control trial**

   Ryan G, Rafferty A, Murphy J, Higgins F, Mangina E, McAuliffe FM

The National Maternity Hospital Inaugural Research Symposium

5. **“VR BABY”, A virtual reality learning environment- does it enhance the understanding and learning of invisible concepts? A randomised control trial**

   (Winner of Research and Innovation award)

   Ryan G, Rafferty A, Murphy J, Higgins F, Mangina E, McAuliffe FM

Poster Presentations

Association for the study of Medical Education (ASME)

1. **Barriers to widespread use of virtual reality learning environments in Obstetrics and Gynaecology**

   Fox L, Ryan G, MacBride C; Higgins M; Mangina E; McAuliffe F

2. **Establishing the reliability and validity of questionnaires assessing the utility of virtual reality in obstetrics and gynaecology education**

   MacBride C, Ryan G, Fox L. Higgins M, Mangina E, McAuliffe F

UCD Conway Festival October 2020

3. **Development of a Virtual Reality Learning Environment: "VR Baby"**

   Ryan G, Murphy J, Higgins F, Mangina E, McAuliffe FM

JOGS Nov 2021

4. **Barriers to widespread use of virtual reality learning environments in Obstetrics and Gynaecology**

   Fox L, Ryan G, MacBride C; Higgins M; Mangina E; McAuliffe F

5. **Establishing the reliability and validity of questionnaires assessing the utility of virtual reality in obstetrics and gynaecology education**

   MacBride C, Ryan G, Fox L. Higgins M, Mangina E, McAuliffe F

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Chapter 1 Introduction

1.1 Background

Medical education and learning are an integral part of medicine which aims to supply society with a knowledgeable and skilled medical workforce who put patient care above self-care and commit to a career of lifelong learning (Swanwick, 2013). Since the establishment of the various groups including the Association for the Study of Medical Education (ASME) in 1957 and disciplines such as educational psychology, there has been growing research in the field of education and learning theories (Swanwick, 2013). We learn in many different ways and learning theories provide the foundation and infrastructure to inform practice and can enhance the efficacy of teaching, learning strategies and the development of educational technology (Kaufman, 2018). The era of the 4th industrial revolution is upon us, with technology becoming a central part of our daily lives (Schwab, 2017). According to the annual report published by the International Association for Medical Education in Europe (AMEE), technology is dramatically changing the way healthcare is practised and delivered, therefore it is important to equip the current and future workforce for this environment (AMEE, 2018).

This chapter begins with a focus on educational technology in undergraduate medical education, specifically immersive technology, including virtual, augmented, and mixed reality. This will be followed by a discussion of the learning theories that support and inform the development of educational virtual technologies, which will be the focus of this thesis, in the format of a conceptual framework and instructional design component that will guide the technical development of the educational virtual learning tool in this thesis. Finally, I will conclude with my proposed hypotheses and outline the objectives and structure of this research thesis.

1.2 Literature review: educational technology overview and current state

1.2.1 History and definition of educational technology

From pen, pencil and books to computers and virtual reality headsets, the use of educational technology to help deliver knowledge and enhance understanding has evolved since the foundations were put in place by the Greeks, who are also thought to have developed the first version of a computer (Norman, 2014). The Oxford English dictionary simply defines educational technology as *"digital technology used to facilitate learning"* (Press).

Educational technology is a discipline that is constantly evolving due to the dynamic nature of the technology industry. As a result, international groups in the field have coined various terminology and definitions to describe educational technology over the years. The International Association for Educational Communications and Technology (AECT), based in the United States of America, is the oldest professional and academic body of educational technologists in the world. The AECT commissioned a book, *Educational Technology: A definition with commentary* (Januszewski and Molenda, 2013), which was a collaborative effort from over 25 expert reviewers in the field and which explored previous and current definitions of educational technology. Educational technology was initially defined as "*a complex and integrated process, involving people, procedures, ideas, devices, and organization for analysing problems and devising, implementing, evaluating, and managing solutions to those problems, involved in all aspects of human learning*" (Januszewski and Molenda, 2013). Most recently, and for the purpose of this research, educational technology has been defined as the "*study and ethical practice of facilitating learning and improving performance by creating, using, and managing*

appropriate technological processes and resources" (Januszewski and Molenda, 2013).

1.2.2 Overview of educational technologies

Educational technologies encompass an array of instructional materials that have been developed over time. They are learning tools that can support medical education. Educational technologies can be separated into conventional and modern forms of instructional materials. Conventional formats include the blackboard, overhead projectors, televisions, and video cassette recorders (VCRs). More modern materials include the computer, various software applications such as liquid crystal display (LCD) projectors, camcorders, digital cameras, scanners, the internet, satellite, interactive TV, audio and video conferencing, artificial intelligence, virtual, augmented, and mixed realities. This is illustrated in Figure 1 below.

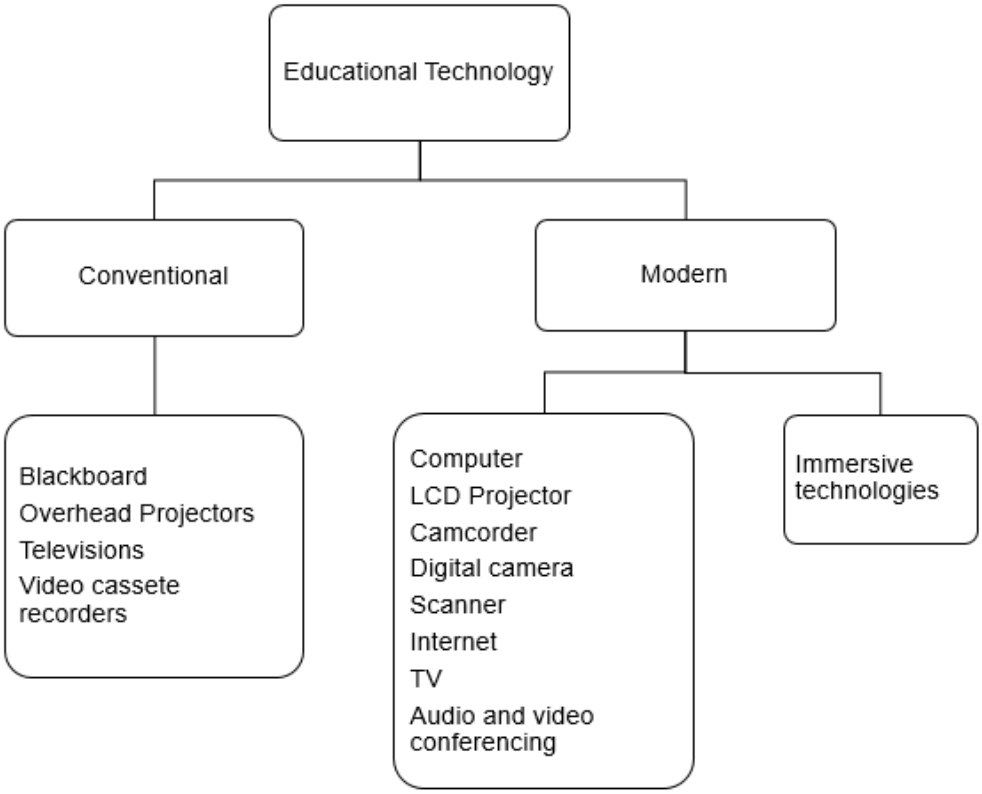


Figure 1 Educational technology divided into conventional and modern formats

1.2.3 Overview of immersive technologies

Immersive technologies can be described as a spectrum of reality, between what is real and what is not; known as the reality-virtuality continuum (Skarbez et al., 2021). This is illustrated in Figure 2 below.

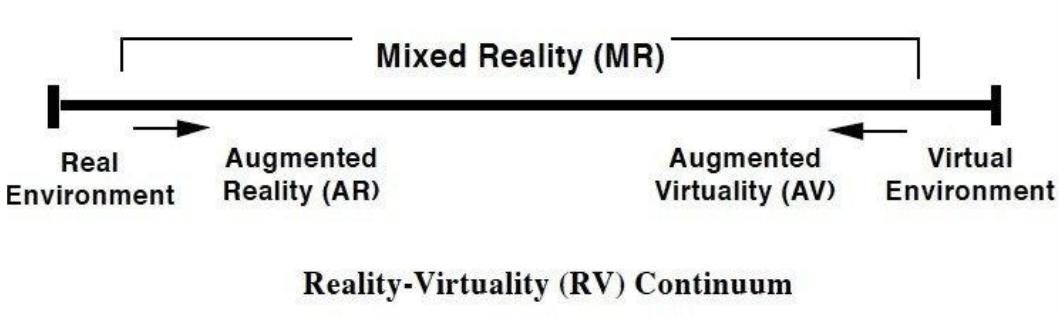


Figure 2 Milgram and Kishino's reality-virtuality continuum (Milgram and Kishino, 1994)

Under the umbrella of educational technology, immersive technologies include Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) (Figure 3). Immersive technologies are exciting and novel educational learning tools that can be used to support teaching and training in medical education. However, immersive technologies are not new and have been used in several industries including the entertainment industry, where they originated in the mid 1960's, in addition to aviation, the military, space exploration, and engineering industries to educate and train working professionals.

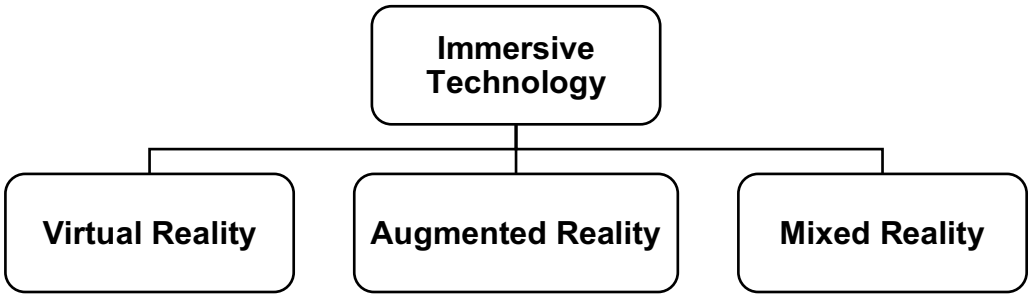


Figure 3 An umbrella flow diagram of immersive technology

1.2.4 Simulation based medical education

To discuss immersive technology further it is important to take a step back and understand why educational tools are used. As medical professionals, the code of ethical practice is defined by the Hippocratic Oath. The ultimate goal of healthcare education is safety and improved outcomes for our patients. Increased focus on patient safety, calls for new training models and standardised educational opportunities has led to the widespread adoption of simulation over the past few decades (Motola et al., 2013). Simulation can be simply defined as "*the imitation of the operation of a real-world process or system over time*" (So et al., 2019). Within healthcare education, cognitive psychology has shown that information is remembered and applied better when it is practiced in environments similar to the workplace (Issenberg et al., 2005).

As is widely known, the work of healthcare professions is heavily dependent on skills and performance-based tasks, in conjunction with non-technical skills, decision making, and clinical reasoning, coupled with integrity, empathy, and compassion (Okuda et al., 2009). Simulation has been used for centuries as a method to teach and train, in addition to bridging the gap from the classroom to the patient bedside (Khan et al., 2011). Simulation engages learners in lifelike experiences to allow persons to experience a representation of a real event for the purpose of learning, practice, evaluation, testing and to gain understanding (So et al., 2019). Simulation facilitates deeper learning using deliberate practice which incorporates interventions grounded in information processing and behavioural theories of skill acquisition, maintenance, and experiential learning. It can also be termed as simulation based medical education (SBME) and includes computer-based simulation, procedural simulation, simulated

patients, simulated clinical immersion and hybrid simulations. More advanced educational technologies that facilitate simulation include virtual patients (VPs), virtual reality learning environments (VRLEs) and virtual classrooms. This thesis will focus on the use of VRLE based simulation as an educational tool.

Simulation is used to teach non-technical skills such as medical knowledge i.e., anatomy, management, situational awareness, communication and teamwork skills, and technical skills such as laparoscopy, emergency drills and clinical skills, without risking any harm to patients (Khan et al., 2011). There is a strong evidence base in the literature to support the use of simulation in healthcare education (Motola et al., 2013, Heskin et al., 2019, Alanazi et al., 2017). When compared to other types of instructional learning it results in positive learning outcomes i.e knowledge improvement, increased satisfaction and enjoyment. Systematic reviews and meta-analysis have demonstrated improved clinical performance when compared to a baseline or no intervention (Cook et al., 2011). Interestingly, within Nursing education, a recent report suggested that simulation can be used to replace up to 50% of clinical based teaching time (Hayden et al., 2014).

Simulation allows the transfer of theoretical knowledge to practice. Simulation based learning is informed by principles from constructivist learning theory, which is built on the idea that students are the creators and construct their own knowledge which is thought to promote a deeper engagement and understanding in the learning process (Motola et al., 2013). Simulation facilitates a self-regulated, learner centred approach to allow the student to learn in this way. Simulation provides a safe and interactive

learning environment that promotes enhanced understanding and performance, with a reduction in errors (Al-Elq, 2007).

It is acknowledged that simulation is considered a successful learning tool, however, the use of simulation is not without its challenges. It is dependent on staffing, available resources, and protected teaching time, which can be a challenge in ever growing and demanding healthcare systems (Martin et al., 2020). Other limitations that are described in the literature mainly relate to operational and participant engagement and cost (Blanié et al., 2020, Battista and Nestel, 2018). Battista (2018) discusses such limitations further in a study on simulation in medical engagement (Battista and Nestel, 2018). Participant engagement is a key aspect of simulation-based learning, some participants may not be willing to get involved in the learning activity therefore affecting learning for potentially all involved. Operational issues may refer to technical and logistical aspects of simulation-based learning. If the equipment fails or breaks, it may be costly and timely to fix. Other challenges can include the resources available including the running costs of simulation and the ability to provide feedback successfully (Battista and Nestel, 2018). These limitations can be addressed by incorporating appropriate educational frameworks informed by learning theories and standards in place, along with the resources to implement simulation-based learning on a more permanent basis within medical education (Motola et al., 2013).

Furthermore, the current global pandemic COVID-19 has highlighted the need for alternative platforms to deliver simulation (Byrnes et al., 2021). Initial research findings suggest that immersive technology provides an alternative platform for simulation training and learning, which can be self-directed or in group circumstances (Barry Issenberg et al., 2005). Immersive technologies can provide an environment to

enhance learning of three-dimensional (3D) concepts and practice instructions in a safe and repetitive manner (Srikong and Wannapiroon, 2020). However, if immersive technologies are to be accepted and adopted into the healthcare education curriculum they need to be developed and implemented based on proven pedagogies and have clear predefined learning objectives, in addition to the educators being trained on how to use them (Rizzetto et al., 2020, Masters et al., 2016).

Various factors have driven the widespread development of immersive educational tools for medical education, including the increased availability of such technology, changes in the way we deliver education, as well as modern day student expectations (Ovunc et al., 2021). Therefore, it must be remembered that educational technology is, not a replacement of the basic elements of mainstream education, but a learning tool to enhance the process. Thus, as research in this field is still relatively new and lacking, a strong evidence base is required to support the effective use of these immersive educational technologies (Kyaw et al., 2019b).

1.2.5 Virtual Reality history and definition

Firstly, let's consider the concept of VR which can be traced back to the early 1900's, where the idea of VR was just a fictional concept (Anderson et al., 2010). Since then, several definitions have been formulated. VR can be described as "*real-time interactive graphics with 3D models, combined with a display technology that gives the user the immersion in the model world and direct manipulation*" (Cipresso et al., 2018). Similarly, VR can be defined as "*The user's senses (sight, hearing and motion) being fully immersed in a synthetic environment that mimics the properties of the real world through high resolution, high refresh rate head-mounted displays, stereo headphones and motion-tracking systems*" (Moro et al., 2017b). From these various

definitions, we will characterise VR as a "*collection of hardware such as Personal Computer (PC), Head Mounted Displays (HMDs) and tracking sensors, as well as software to deliver an immersive experience*" (Hussein and Nätterdal, 2015).

There are a variety of VR technologies, ranging from 3D computer based applications, web based virtual worlds, 360-degree videos, virtual patients, fully immersive VR learning environments, which incorporate the use of a headset to Cave Automatic Virtual Environments (CAVE) and virtual telepresence systems that facilitate distant learning or collaboration in the surgical field (Pottle, 2019). Figure 4 illustrates a user wearing a VR headset, with the screen in the background showing what the user sees in the headset.



Figure 4 A demonstration of a user wearing a virtual reality headset

Now that we have defined VR, we will discuss the components that are required to create VR. A VR system is comprised of three main components: Immersion, Perception, and Telepresence (see Figure 5 below).

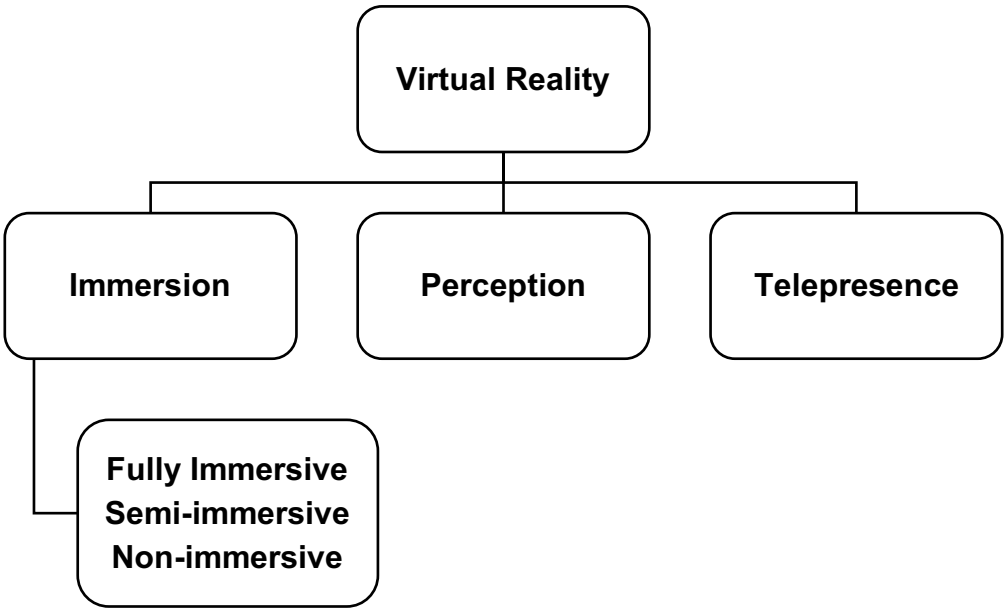


Figure 5 The components of virtual reality

Firstly, I will take the concept of immersion which empowers the user to feel captivated in a suspension of disbelief (Pantelidis et al., 2018); in other words, the feeling of being physically present in an imaginary world. There are three different levels of immersion, which also help to delineate between the types of VR technologies available, including non-immersive, semi-immersive, and fully immersive. Non immersive systems include desktops, which are not very sophisticated devices for VR, whereas fully immersive systems, such as a headset, provide the user with the closest experience to reality through delivery of high-quality graphics and performance. This usually involves wearing a headset that places the user in an environment that is not real.

With a VR headset, such as the Oculus Quest (a VR headset developed by Oculus, a company of Facebook Technologies, LLC), you place it on your head and are immediately transported out of your own real surroundings into an alternate reality. For example, you can go to Egypt and take a tour of the famous pyramids or Niagara Falls in the United States of America (USA). Lastly, a semi-immersive system is a VR

experience that is in between an immersive and non-immersive state (Pantelidis et al., 2018).

A good example is a flight simulator, providing an immersive experience incorporating high performance software with stereoscopic vision, increased field of view, and haptic feedback. Haptic feedback refers to a type of touch technology that uses motion or vibrations for example to communicate with the user. Secondly, perception refers to one's awareness of their surroundings through the physical senses. VR uses hardware to relay computerised 3D images and audio, which is realistic and simulates both real and abstract structures. Lastly, telepresence refers to the idea that motion of the user should be detectable so that the visual field and auditory stimuli can change accordingly (Srikong and Wannapiroon, 2020). The user must be able to both affect the virtual environment and be affected themselves via haptic feedback stimuli. Haptic devices, such as joysticks and gloves, provide such feedback (Pantelidis et al., 2018). These key components contribute to making VR an immersive experience. VR has been portrayed in film and literature for many years and now science-fiction has caught up with reality, with the wide use of VR across many industries including entertainment and gaming, engineering, aviation, and education. This technology may change the way people learn and live in the future, for example medical students may use VR laparoscopic trainers as a standard training tool to develop surgical skills in the future, with the reduction in availability of cadavers' anatomy may be learned through VR and AR applications (Bainbridge, 2007).

VR has evolved through the centuries in various industries, most notably in the film and aviation industries. The earliest attempts of VR date back to the nineteenth century, of panoramic murals, which are 360-degree paintings that gave the

impression that the user was also present in the painting. This concept pertained to the idea that VR can create an illusion. The next step in the development of VR came from Charles Wheatstone in 1838, a famous scientist most noted for his invention of the stereoscope, a device used to view 3D images (see Figure 6). His research concentrated on how the brain processes two-dimensional (2D) into 3D images. The invention of the stereoscope to visualise 3D images contributed to the design principles of modern VR devices.



Figure 6 A stereoscope

The next advancement in the development of VR was the visualisation of images in 3D. In the 1950's, Hollywood set the scene for the development of one of the earliest VR devices, a camera that showed a movie in 3D. Morton Heilig, a cinematographer, developed the Sensorama, a virtual theatre cabinet to show movies (see Figure 7). It was a camera that the user looked into in order to see 3D images. The device could stimulate the visual, audio, haptic, and olfactory senses of the user to deliver an immersive experience (Allison, 2008).

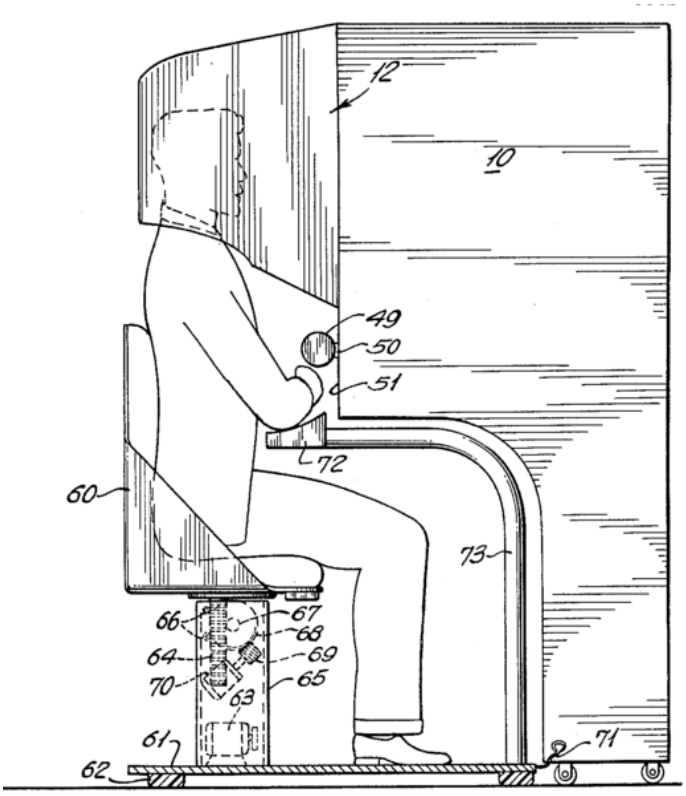


Figure 7 Morton Heilig's Sensorama (Wikipedia, 2008)

The next major advancement in VR was the development of Head Mounted Displays (HMDs), which came onto the scene in 1961, when Dr. Ivan Sutherland, a computer scientist, invented "*BOOM*" (Binocular Omni Orientation Monitor). BOOM was a HMD that tracked both the position of the user, along with the user's eyes, and updated the image of its stereoscopic view according to the user's position (Sutherland, 1968). This invention formed the basic concepts of VR, namely immersion, perception, and telepresence.

In 1987, the term VR was born and, since then, technology has advanced HMDs to the present day. The multi-billion-dollar gaming industry has played a key role in the evolution of VR. When HMDs were first developed, they were connected to a computer system. Now with the advancement of technology, there are stand-alone headsets

available for commercial use on the market. Popular VR Headsets include the Oculus Quest, HTC Vive (HTC Corporation), and the Sony PlayStation VR (Smutny et al., 2019). As a result, various industries have since adapted the use of VR as a training tool, which has become much more feasible with cost effective products now available on the market. For example, in the aviation industry pilots have been training using simulators for years and have incorporated VR into their training practices (Weirauch, 2020). This has led to a reported 50% reduction in error-related airplane crashes since the 1970s (Bremner et al., 2020). Similarly, the military (Lele, 2013) and the National Aeronautics and Space Administration (NASA) (Carson, 2015) have benefited from VR technology to provide a safe environment for training and practice.

Another industry that has used VR is engineering, designing projects in 3D to help identify any defects or risks before any building commences in reality (Alfalah, 2018). The sporting world is also no stranger to the use of VR. Formula 1 is currently pioneering the use of the most up to date VR technology, which reduces training time for the drivers and costs simultaneously. Toto Wolff, the team principal of Mercedes Formula One team, explained in an interview with Wareable, a website dedicated to wearable technology, that "*The better you can simulate what is happening on track, the quicker it's going to make you*" (Johnson, 2017). The use of this technology has, therefore, generated considerable interest across all industries, including medical education and its potential to supplement current teaching in education is exciting.

VR technology can be used in different formats, it can be divided into VR in a computer setting (semi-immersive) or VR in a headset (fully immersive). A computer web setting can provide a platform for displaying objects in 3D or three-dimensional virtual worlds (3DVWs). VR headsets can provide a fully immersive virtual environment known as a

VRLE. These virtual environments can be used as a platform for creating virtual lessons, virtual patient (VP) encounters or simulating a clinical task or visualising complex topics. Figure 8 simplifies the VR technology that will be described further in subsequent sections of this chapter, particularly as it applies to the field of healthcare, and healthcare education, with a particular emphasis on undergraduate education.

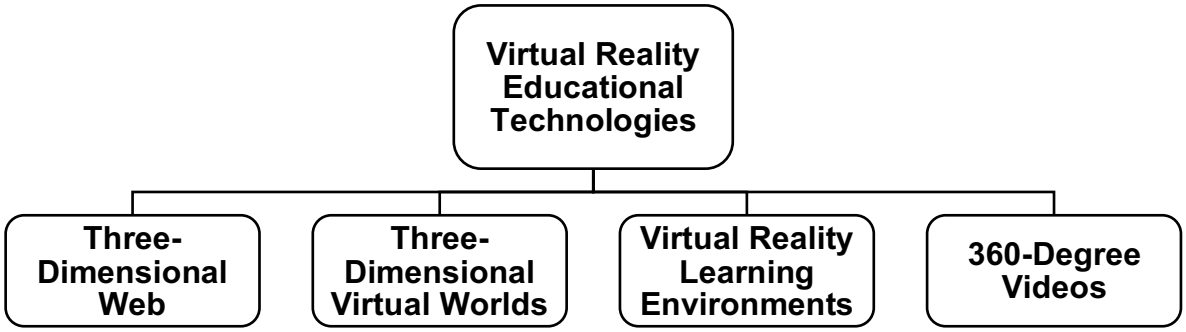


Figure 8 VR Educational tools

1.2.6 Augmented reality history and definition

AR, in comparison to VR, is an interactive experience of a real-world environment where the objects that reside in the real world are "*augmented*" by computer-generated perceptual information. AR supplements the real world with 3D objects, using a camera and screen (i.e., smartphone or tablet) (Tang et al., 2020). In other words, the aim of AR is to remain present in the user's reality and superimpose 3D interactive objects into the field of view. AR applications can be run on several devices, including tablets, mobile phones, AR glasses, and other optimized devices.

Historically, the development of AR started in the 1960's, alongside the concepts of VR, but the term augmented reality was established in 1990 when Thomas P. Caudell, of Boeing, coined the phrase. The first AR device was developed by researchers at the Armstrong research lab (USAF) at Brooks Air Force Case, San Antonio, Texas. The device was known as "*Virtual Fixtures*" and was a robotic device capable of high-speed 3D graphics processing power used to assist the user in carrying out tasks (Norman, 2014).

Like VR, the advancement of the technology industry brought about the widespread availability and increased use of AR. The next evolutionary step for AR was the development of an outdoor mobile AR game entitled ARQuake over twenty years ago. Adobe Flash went on to introduce the ARtoolkit, a designing tool in 2009. Google took over the field with the revolutionary invention of Google glass in 2013, hands-free smart glasses, with functions similar to a smart phone. Google glass has been used in various educational settings, including engineering, science, humanities, the arts and, indeed, healthcare (Brewer et al., 2016). Although AR technology is advancing all the time, with some AR devices available on the market, they are still quite costly. AR headsets like MagicLeap2 or the HoloLens 2 are approximately $3000 (CNET, 2022). Research in the area of AR in medical education is still relatively new compared to VR, which I will discuss later on in this section, however it is growing quickly.

1.2.7 Mixed reality definition

MR can be described as the merging of real and virtual worlds to produce new environments and visualisations, where physical and digital objects can co-exist and interact in real time. MR is a blend of VR and AR which combines the interaction between human, computer, and the environment. MR is capable of affecting industries

across the board, from entertainment, to engineering practices. MR can make a hologram appear on a stage or add interactive props to a concert. In engineering, MR can assist in planning and designing of infrastructure, provide remote working opportunities and help train employees (Marr, 2020).

1.3 Immersive educational technologies in medical education

Regarding medical education, changes in teaching strategies over time, and financial pressures, have all contributed to the need for alternative teaching and learning solutions. VR offers a safe environment for repetitive practice of clinical skills without risk to patients, this raises the idea of a safe place to fail. This is an important concept to consider in education as a skill is learned and therefore it is likely there will be failure when the learner is practicing and learning. The idea of allowing failure in training and practice is considered essential to the learning process as it can be a powerful teacher and motivate students to repeat practice until the skill is developed, facilitating independent practice (Klasen and Lingard, 2019). VR also provides an alternative solution for training at any-time, regardless of location, or whether one is alone or in a group setting (Dunleavy et al., 2019). VR technology is also beneficial for visual learners, or learners with poor spatial abilities, by enhancing understanding of concepts that require 3D visualisation in the topic of anatomy, for example (Downer et al., 2020). Disadvantages include the high costs of setting up VRLEs, as well as the side-effects of VR including cybersickness, and the current lack of evidence-based research for its addition to the curriculum (Samadbeik et al., 2018).

1.3.1. Virtual reality in medical education

At undergraduate level of medical education, VR research demonstrates an effective medium to enhance the performance of students in select areas within the curriculum.

The literature suggests that the main area of impact with VR technology is anatomy education, basic clinical skills, and surgical skills (Zhao et al., 2020, Dyer et al., 2018). Research is increasingly demonstrating that VR technology can enhance understanding, engagement and self-confidence in learning (Kyaw et al., 2019b).

1.3.1.1 Virtual reality in undergraduate medical education

There are a variety of VR tools and applications that have been developed, from 3D objects that can be interactive and manipulated for learning on a desktop, to 360 Degree Virtual videos, and immersive VRLEs to virtual patients. The value of VR tools lies in the ability to design and construct environments specific to the needs of the user. This allows development of educational tools with predefined learning objectives. With this in mind, I will explore the literature on how VR is changing the face of anatomy education and go on to discuss the use of 3DVWs in medical education and the supporting learning theories.

1.3.1.1.1 Virtual reality and anatomy education

In anatomical medical education, there seems to be a huge potential for the use of VR technologies based on the published literature. Challenges within the domain of anatomy education (Clunie et al., 2018), including the availability and accessibility of cadavers (McLachlan and Patten, 2006), the modern anatomy curriculum (Louw et al., 2009), increasing medical student numbers, as well as decreased teaching hours have led to the development of alternative tools to support learning in this subject (Chen et al., 2020). Two studies demonstrated the reduction of teaching time within the gross anatomy curriculum, in the United States, concluding that, over the last 50 years, there has been a decrease by 55%; a similar result was found in Australia and New Zealand (Drake et al., 2009).

Educators and students have used various educational technologies such as online videos and podcasts to supplement their knowledge. With the advancement of technology, VR provides the perfect platform for human anatomy to be viewed in 3D computer application or a VRLE. Furthermore, within subjects like anatomy and physiology, there are many complex concepts that could be more easily understood with 3D visualisation (Hampton and Sung, 2010). Examples of complex concepts include fetal development in embryology, the female pelvic floor and its associated dysfunction, various body systems such as the heart and its associated physiology or congenital anomalies, the blood supply in the brain known as the circle of Willis or the kidney and the physiology of the nephron.

Students are often required to take 2D objects in a textbook and translate them into 3D objects in their mind, which can be a significant cognitive leap for some students (Marsh et al., 2008a). Students may also mentally rotate complex structures inaccurately, leaving the mind to fill the gaps of any missing structures (Liesefeld et al., 2015). This can lead to a poor or incorrect understanding of the subject, with potential implications in future clinical practice (Brewer et al., 2012a). VR offers an alternative solution for this issue, one that could automatically standardise this process for students and enhance understanding for long-term memory (Ekstrand et al., 2018). VRLEs could standardise this process of 3D visualisation and enhance understanding, promoting deeper and longer-term knowledge retention, and spatial understanding of structures in relation to other structures, especially in students with lower spatial abilities (Stepan et al., 2017c, Gonzales et al., 2018, Bogomolova et al., 2019).

The last decade has seen an exponential increase in publications documenting the development and assessment of VR technologies including web applications and

VRLEs that demonstrate effectiveness in teaching anatomy (Maresky et al., 2019b, Wang et al., 2020, Chen et al., 2020, Maniam et al., 2020a, Erolin, 2019). A meta-analysis exploring the effectiveness of three-dimensional visualisation technology (3DVT), which included tools such as VRLEs and 3D web applications concluded 3DVT is an effective method of increasing knowledge (effect size of 0.50) and spatial relationships (effect size of 0.30) in anatomy education (Yammine and Violato, 2015).

In addition, it is thought that 3DVT can assist learners with low spatial abilities. A more recent systematic review and meta-analysis, by Zhao (2020), also concluded VR is an efficient way to improve anatomy knowledge (Zhao et al., 2020). Of 15 randomised controlled trials, analyses showed that VR improves test scores moderately compared with other approaches in the random effects model (SMD =0.53; p<0.01). The study included trials that compared VR to traditional learning methods such as lecture, dissection and/or textbooks. Five studies assessed learner satisfaction; the pooled results based on the fixed effects model demonstrated that the majority of students favoured learning anatomy via VR methods rather than traditional methods (SMD=0.77; p<0.05). The study concludes that VR can potentially improve teaching effectiveness of anatomy, however due to the lack of standardised measurement tools and heterogeneity of studies more research using standardised assessment tools is required for future validation of VR as an educational tool.

Therefore, VR technologies such as VRLEs may provide a key learning support in the subjects that require visualisation of 3D objects and spatial awareness. In embryology education, which is very important for Obstetrics and Gynaecology education, there are complex concepts that require the same visualisation capabilities as discussed above. There is a lack of literature on the topic of VRLEs as a platform to support

educators in teaching embryology education and in Obstetrics and Gynaecology education, which is a key point of interest in this thesis. Several studies have attempted to develop VRLEs for embryology education. However, there has been no attempt to evaluate the learning outcomes on this topic.

1.3.1.2 Three-dimensional virtual worlds in medical education

A systematic review of 62 papers on the use of 3DVWs in healthcare, explored the categories of healthcare they are being used in, their context in each field and their contributions to these categories. Authors identified six main categories that 3DWVs were used for in the healthcare setting: academic education, professional education, treatment, evaluation, lifestyle, and modelling. Within the treatment category 3DVWs are being used within the domain of psychology to treat post-traumatic stress disorder for example. Within the modelling category, a study used simulation to model a hospital for training purposes (Boulos et al., 2007). In the evaluation category, nursing studies have developed 3DVWs for development of decision-making skills (McCallum et al., 2011). This study provided a large database on the use of 3DVWs in healthcare and demonstrates the diversity of 3DVWs from health and safety models to training decision making skills amongst healthcare professionals. The authors concluded that pedagogical uses were the most importance applications of 3DWVs in health care and the study is a potential resource for healthcare professionals on the use of 3DWVs (Ghanbarzadeh et al., 2014).

Virtual worlds provide a creative and powerful environment that promotes communication, collaboration and team-working skills (Ghanbarzadeh et al., 2014). Virtual worlds are a platform for distance learning, online conferences and even medical schools. The current global pandemic has highlighted clear benefits of virtual

worlds to support collaboration and communication when we physically cannot meet face-to-face (Gordon et al., 2020). For the full benefits of virtual worlds, both the user and educator require training to operate and utilise 3DVW's for its adoption into practice, followed by further robust randomised controlled trials (RCTs) to assess the effectiveness in medication education. However, this can be a challenge when implementing a new technology.

Boulos (2007) reviewed the literature on 3DVWs, exploring their role and potential in the field of medical education (Boulos et al., 2007). 3DVWs can provide a rich and enhanced learning experience for todays' learners of Generation X and Y. It is thought to encourage an active learning experience, in addition to increasing creativity, social skills and independent problem-solving skills (Boulos et al., 2007). Conversely, at the same time, Hansen (2008) detailed a critical overview of 3DVWs used in health care professional education and medicine and presented the fundamental design, evaluation and pedagogical challenges that faced its implementation into the curriculum. The study concluded that 3DVW's presented an environment for learning in healthcare education however more analysis was required (Hansen, 2008). Over ten years later, a review was published, that examined the educational outcomes of higher education students using 3DVW (Ghanbarzadeh et al., 2014). They found 18 positive outcomes which were further characterised into 8 categories, namely satisfaction, positive learning outcomes, engagement, learning style, environmental impact, retention, skill development, and connectedness. They conclude an overall high level of satisfaction and acceptance of this technology, furthermore in terms of educational outcomes they report enhanced learning performance and effective learning (Ghanbarzadeh and Ghapanchi, 2021).

As a user, one can train for mass casualties (Farra et al., 2013), practice surgical skills, and perform physical examinations on a patient in a virtual world (Hansen, 2008). 3DVWs offer great opportunities for healthcare professional education and have already been used in this field, especially since it has become more affordable (Ghanbarzadeh et al., 2014).

Examples of 3DVWs include Forterra's OLIVE, The Croquet Consortium, Sun Microsystem's Project Wonderland, ProtonMedia's Protosphere and Linden Lab's Second Life (Ghanbarzadeh et al., 2014). 3DVWs provide a platform for social networking and communication and training. Second Life (SL) is the most well-known virtual environment, which is accessible by downloading a free computer software programme. It was developed by Linden Lab, in San Francisco, USA in 2003. The virtual world is made up of an environment that simulates Earth, divided into regions where the user enters as an avatar. It has been used to provide a platform for virtual patients for basic patient history-taking skills and to deliver educational programmes on topics such as mass casualty training and Sexual Health (Boulos et al., 2007, Boulos and Toth-Cohen, 2009, Toro-Troconis et al., 2008).

Furthermore, organisations across various fields including medicine, medical education, and engineering have held their annual conferences using 3DVW in the last year due to the global pandemic COVID-19. This highlights another benefit of 3DVW as a platform for research dissemination, which enabled this author to disseminate research findings over the last year, including most recently an oral presentation of my RCT at the Royal College of Obstetrics and Gynaecology (RCOG) Virtual World Congress on the 12th of June (RCOG, 2021). Figure 9 depicts my attendance at the 6th International Conference of the Immersive Learning Research

Network (iLRN), The Institute of Electrical and Electronic Engineers organisation (IEEE) in June 2020. I presented my abstract on the "*Development of a VR Learning Environment: "VR Baby"* in a 3DVW where participants were represented as virtual "*avatar*s". Another example includes the ASME Annual Scholarship Meeting 2020 "*Disrupting Medical Education"* which was also held virtually and where participants also had virtual "*avatars*" (2020). Avatars are described as 3D virtual characters which can be placed in a virtual world. Nintendo has also developed medical games for surgical training; "*Trauma Center: Second Opinion*", affording players of the game the opportunity to be a surgeon on Wii by using the Wii mote (Overtoom et al., 2017). The intuitive nature of the Wii mote, an accessory controller, allows for experiential learning and the gaming factor may evoke competitiveness, fun, and active learning.



Figure 1 Presenting my abstract "Development of a VR Learning Environment: "VR Baby" in a 3DVW at the 2020 6th International Conference of the Immersive Learning Research Network, The Institute of Electrical and Electronic Engineers Organisation

1.3.1.3 Current use of virtual reality in medical education

Taking it a step further, it is possible to attend medical school (or, at least part of it) in SL. Online learning tools have been developed for medical and nursing students at Imperial College London, UK, the University of Northampton and the University of Oxford where students can practice their basic clinical skills in a virtual hospital and earn credits (Pottle, 2019). At Imperial College London, a multidisciplinary team consisting of doctors, videographers, graphic designers, and technical staff built a hospital in SL. The hospital is used for healthcare training purposes. The learner's active participation in a virtual world is thought to encourage awareness, team cooperation, and decision-making skills (Dev et al., 2007). In a pilot programme, third

year medical students were given access to virtual patients on a respiratory ward to practice basic clinical skills (Hansen, 2008). The completed surveys on their attitude and opinion on the learning experience. The results of the attitude survey were favourable of SL and the feedback provided informed the next stage of development. This study provided the framework for the development and design of VPs to learn basic clinical skills in VR, based on established pedagogies (Toro-Troconis et al., 2008).

1.3.1.3.1 Virtual reality CAVEs in medical education

Another VR related technology worth mentioning is the “CAVE”. A “CAVE” is a room that houses the VR software and provides a space for using the VR headsets and allows someone to also monitor the use of the VR headset safely. Numerous universities in England have built and developed a purpose built “CAVE” to use as a teaching tool across several disciplines including medicine. VR learning modules to teach anatomy have already been implemented at several universities around the world, including Australia’s Monash University, University of California San Francisco, Stanford University, Cleveland Clinic Lerner College of Medicine and University of Illinois College of Medicine Peoria (Zweifach and Triola, 2019).

Describing how this was developed in University of California, San Francisco (UCSF), Baker (2017) explained how VR is revolutionising anatomy education: “*Wearing virtual reality goggles, Jordan Holler was hard at work taking apart muscles inside of a body. The first-year medical student at UC San Francisco wasn’t touching any real tissues, though. He was using new technology that allowed him to put on a headset and start to “move” anatomy, revealing layers and structures. Then the virtual reality program can be reset to do it over in a new way*” (Baker, 2017) (see Figure 10).



Figure 2 Medical student using a virtual reality headset at the University of California San Francisco Anatomy Learning Centre (Baker, 2017)

1.3.1.4 Virtual Reality in postgraduate medical education

At postgraduate level, VR technology has been adopted in surgical and medical residency programs for various skill development and training (Ahlberg et al., 2007, Gurusamy et al., 2008). Examples of VR systems include injection simulation training systems (Lai and Chang), bronchoscopy surgery simulation systems (Krogh et al., 2013), sigmoidoscopy operation simulation systems (Gerson and Van Dam, 2004), gynaecology surgery simulation system (Gala et al., 2013), EndoVR endoscopy computer simulation teaching system (Khan et al., 2018), LapVR laparoscopic computer simulation teaching system (Lesch et al., 2020), MIST-VR laparoscopic trainer (Portelli et al., 2020), and CathLabVR catheter interventional treatment computer simulation (Jensen et al., 2014).

A detailed recent systematic review and meta-analysis, Alaker (2016), analysed 31 RCTs with the aim of comparing VR simulation to no training, box trainers, and to video trainers (Alaker et al., 2016). The meta-analysis revealed that proficiency-based VR training is significantly more effective when compared to video trainers and at least

as good as box trainers for laparoscopic surgical skill development. The study concluded that proficiency-based VR training is an effective and necessary educational tool that should be implemented into surgical training programmes (Alaker et al., 2016). VR has widely been adapted in surgical training programmes with good results (Bric et al., 2014, Raza et al., 2014, Kang et al., 2015).

1.3.2 Augmented reality in medical education

Recently, there has been an explosion of research on the topic of AR in Medical Education in the last decade, partly due to the increased availability and feasibility of AR devices like the HoloLens (by Microsoft). AR provides a unique immersive learning experience that may have less side-effects than VR, in that it does not fully immerse you in a new environment. Research has shown AR to be an enjoyable learning experience, that can build knowledge and enhance understanding in the subject of anatomy (Moro et al., 2017b). A recent systematic review investigated the current status of AR applications in medical education. The review found that AR is used in two main areas of medical education: surgical skills training and anatomy education (Tang et al., 2020). AR devices have been developed and shown to effectively teach suturing, surgical procedures such as colectomies and other laparoscopic tasks (Botden et al., 2009). With regard to anatomy education, studies carried out on applications such as AR Magic Book, and Microsoft Kinect; demonstrated improved knowledge and learning experience (Ferrer-Torregrosa et al., 2016, Kugelmann et al., 2018). An image of an AR device used for anatomy education is illustrated in Figure 11.

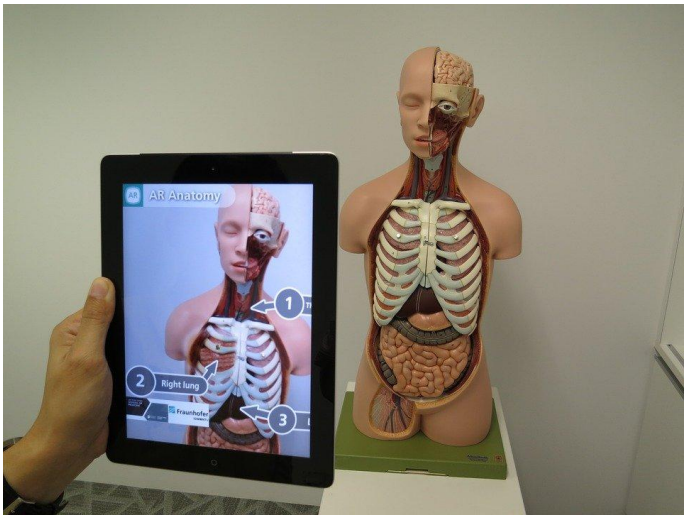


Figure 3 Augmented reality for anatomy education (Pixabay, 2017)

The literature on AR, thus far, is illustrating the enhanced learning environment that this technology creates for repetitive practice of basic clinical skills, surgical skills, and non-technical skills such as communication which apply concepts from the behaviourism, cognitivist, and constructivism theories. A recent RCT demonstrated the effectiveness of AR in improving surgical skills of resident doctors (Lohre et al., 2020). A multi-site RCT also found similar results of higher levels of self-confidence and knowledge in surgical skills (Pulijala et al., 2018). Furthermore, communication skills have been improved using immersive technologies, and research has been carried exploring immersive technologies to teach empathy and delivery of bad news (Dyer et al., 2018). Simulation involving AR can also provide a safe environment for deliberative and repetitive practice. However, although AR has great potential for education and training purposes in medical education, the research is still in its infancy today, due to the cost and ability to make applications universally available. Thus, in order to incorporate it into healthcare education at both undergraduate and postgraduate level there needs to be more development and research to develop a strong evidence base for its use (Tang et al., 2020).

1.3.3 Mixed Reality in medical education

MR, whilst still in its infancy today, has huge potential in the future of medical education. For similar reasons as outlined above for VR, there is a demand in medical education for alternative educational tools. There have already been studies demonstrating the benefits of MR for surgical education, basic clinical skills, communication skills and anatomy education (Maniam et al., 2020a, Turini et al., 2018). An RCT was carried out with medical students undertaking a urology rotation, comparing a MR learning tool and a traditional instructor to learn the skill of urinary catheter placement. Learning objectives were evaluated via objective structured clinical examinations (OSCE). Results revealed increased learning outcomes in the MR group and similar outcomes to the control group in relation to self-evaluation of the learning tool (Schoeb et al., 2020).

Another study demonstrated the use of MR as a communication tool. Neurosurgeons set out to use an MR tool called “VIPAR” to collaborate on a surgery from a Children’s Hospital in Ho Chi Minh City, Vietnam, and Birmingham, Alabama, at the same time. The study found the MR tool “VIPAR” to be effective in providing international intraoperative assistance (Davis et al., 2016). In anatomy education, cadavers are considered the gold standard for learning practices (Moro et al., 2017c). However, due to reduced access to cadavers, decreased teaching time, and an increase in medical student class sizes alternative learning tools such as MR offer an ideal pedagogical solution (Moro et al., 2017c). Research has already demonstrated the effectiveness of VR and AR for teaching anatomy (Zhao et al., 2020), MR may provide an enhanced solution, as it blends the real and digital world employing a reality-virtuality continuum. In addition, it allows for group learning to take place with the instructor, unlike VR where learning is individualised and therefore potentially more constructivist. Maniam

(2020), detailed the development of a prototype MR learning tool to teach temporal bone anatomy. Through multidisciplinary team efforts, they developed an interactive MR learning tool for temporal bone anatomy education (Maniam et al., 2020b).

Other innovative efforts highlighting the potential of MR include the gross anatomy models developed by the Cleveland group at Case Western Reserve University and the LINDSAY Virtual Human Project, which includes the anARtomy application, an AR device developed at the University of Calgary (Tworek et al., 2013). The advantage of AR and MR educational technologies is the ability to stay in the real world and superimpose 3D objects, as opposed to requiring full immersion in VR. As mentioned previously, I will focus on VRLEs as opposed to AR and MR mainly due to the relevance to Obstetrics and Gynaecology education and also the availability of AR and MR technology and the resources required to develop content for these tools. Like AR, MR is still a relatively new concept in the testing phase, which is reflected in the paucity of publications in the literature on the topic. As such, to establish its effectiveness and feasibility in medical education, further research is required using MR.

1.4 Immersive educational technology in healthcare

1.4.1 Virtual reality in healthcare

From the discussion above, over the last decade, there has been considerable interest from the medical and public health communities in using VR for teaching and training in undergraduate and postgraduate education. Various factors have contributed to the increased use of educational tools such as VR, including pressures on healthcare service provision, the introduction of the European Working Time Directive and an increase in medical students at university, and most recently, the global coronavirus pandemic (Pottle, 2019, Iskander, 2014). VR is an educational technology that is

becoming more widely available due to the release of commercially affordable VR headsets that can be used to create VRLEs, 3DVWs and VPs.

In relation to patient care, VR technology has been used as a therapy in stroke rehabilitation and upper limb recovery (Laver et al., 2017). A Cochrane review of VR as a treatment approach was conducted recently, with the objective of investigating the efficacy of VR as a treatment for stroke compared to alternative or no interventions. 72 trials were included in the review, and it found that the addition of a virtual reality intervention to usual care did not result in more effective upper limb function when compared to conventional therapies. This Cochrane review is an updated version from 2011 to 2015 and included more studies, and it remains consistent in the review that VR is a promising tool as a treatment for stroke however it needs further studies with standardised assessment tools for the validity of its use (Laver et al., 2017). Another study demonstrated the use of VR to reduce preoperative patient anxiety in women undergoing gynaecology procedures (Chan et al., 2020). Subjects were exposed to a VR headset that had a number of relaxing environments and music to choose from for a 10-minute period preoperatively. Pre and post intervention assessments of anxiety were carried out using the Hospital Anxiety and Depression Scale. Data of 108 patients was analysed and found that there was a statistically significant reduction in pre-operative levels of anxiety ($p<0.0001$). The study concluded that VR could be a potentially useful non-pharmacological method of reducing anxiety pre-operatively and avoiding potential side-effects of anxiolytic medications (Chan et al., 2020). However, it is also worth noting that they did not assess the side effects of VR, which is an important factor to consider in using this intervention.

Other areas of medicine using VR technology include psychiatry and palliative care. VR technology is being trialled for treatment of mental health conditions including post-traumatic stress disorder (Gonçalves et al., 2012). In the United Kingdom (UK), the National Institute for Health Research has funded a project worth £4.4m, for the development of VR as a psychiatric therapy for the management of psychosis (Freeman et al., 2022). However, there is a paucity of information on the benefit of VRLEs as a patient education tool.

Within Obstetrics and Gynaecology, there have been very few studies documenting the use of VR technology for patient care or education. Ultrasound is the main imaging modality used in this domain of healthcare. It is widely used in the two-dimensional (2D) mode, and the 3D mode is being increasingly used, for example to take 3D ultrasound pictures that are printed on 2D paper. In the field of fetal medicine, congenital anomalies are diagnosed and managed by specialised Obstetricians. Congenital anomalies occur in 2-4% of live births, with most diagnosed in the prenatal period (Marokakis et al., 2016). A diagnosis of a congenital abnormality in the prenatal period can have significant emotional and psychological consequences for the parents. For clinicians, managing these cases can be complex and challenging, requiring multidisciplinary team (MDT) input. Parents faced with complex diagnoses of congenital abnormalities; can often struggle to comprehend what their baby looks like in the womb. VR technology could provide a visual image for parents, which could help to enhance understanding of what their baby looks like in the womb (Werner et al., 2017). The potential of VRLEs to play a role in patient care and offer treatments for patients is significant, coupled with the opportunity to improve patient outcomes.

VR is also showing promise in relation to decision-making and perioperative surgical planning (Parkhomenko et al., 2019). On a national level here in Ireland, at Our Lady's Children Hospital, Crumlin, Dublin Ireland, Professor Colin McMahon has utilised Computed Tomography and VR technology to display the hearts of paediatric patients with congenital heart disease for perioperative planning, to help rehearse the surgical procedure (Campbell et al.).

1.4.2 Augmented reality in healthcare

AR in healthcare is used in the field of surgery at present. A recent systematic review explored the current status of AR in surgical training and compared benefits with traditional techniques (Williams et al., 2020). The study included human clinical trials and AR was found to be used as a simulator-based platform for laparoscopic skill development or as an intraoperative navigation system. Of 18 publications, all studies showed no difference or improved performance when using AR compared to traditional techniques. Based on the findings that only two studies took place in real clinical settings, AR is still considered an experimental technique in surgery at this point. Benefits of improved trainee technical performance was also highlighted and the need for further research to collaborate and validate these findings (Williams et al., 2020). Other AR surgical applications include the ImmersiveTouch System, used in neurosurgical training (Yudkowsky et al., 2013) and the EyeSI AR Binocular Indirect Ophthalmoscopy (BIO) Simulator a training tool for ophthalmoscopy (Rai et al., 2017). In 2015, Microsoft stepped to the forefront of AR developing a headset, the HoloLens. Various applications have been made for the HoloLens from virtual assistants to anatomy education (Huang et al., 2019).

1.5 Factors influencing immersive educational technologies in medical education

The traditional medical education system has produced generations of high-quality physicians with a firm foundation in the sciences combined with clinical competencies, that have been serving the community throughout the 20th Century (Buja, 2019). So why is there a need to change and adapt new methods of education, more specifically new immersive forms of ET. I previously mentioned that we are now thought to be living in the 4th era of an industrial revolution. Announced by Schwab, the founder and executive chairman of the World Economic Forum, this new era represents a fundamental change in the way we live work and relate to one another with regard to a rapid advancement in technology due to an increased amount of interconnectivity and smart automation (Schwab, 2017).

Various components of medical education are leading to changes that are driving a major transformation, namely changes in training standards, the changing nature of health care delivery systems, the changes in curriculum coupled with the new generation of learners, and the advancement of technology (Han et al., 2019b). In an effort to guide and inform the adoption of educational technology AMEE has setup of a dedicated committee for the field, entitled Technology Enhanced Learning (TEL) Committee (AMEE, 2018). The committee has created innovative approaches such as grants to encourage the development and implantation of educational technology.

1.5.1 Changes in training standards and guidelines on educational technology

The educational landscape is a dynamic environment that is constantly evolving alongside the advancement of the technology industry as demonstrated above in the review of educational technology. Educational technology has become part of the

mainstream support system in medical education, for example using our mobile phones to access UpToDate, an evidence based medical reference application (Oliveira et al., 2019). According to research carried out in the UK, 96% of universities and 79% of colleges are now using virtual or augmented reality in some form (Hamilton et al., 2021). The Association of Medical Educators in Europe (AMEE) have published guidelines for medical educators on the topic of e-Learning (AMEE Guide No.32) (Ellaway and Masters, 2008) and mobile technologies (AMEE Guide No.105) (Masters et al., 2016) in an effort to support educators and curricula developers alike. The scope of these guidelines includes all forms of e-learning and mobile technologies, from computers to mobile devices to wearable VR/AR headsets.

These guidelines are a resource to assist the development of educational tools for use in medical education, from an instructional design component and learning theories to socio-theoretical concepts that underpin educational technology. The theoretical component of supporting the development of educational technology will be discussed further in the next section. The guidelines acknowledge that this is a complex and evolving area within medical education, which calls for creativity and adaptability in response to the situation, as there are no set practices. These guides aim to ameliorate the technology in support of the teacher, with the primary focus being the learner.

1.5.2 Changing nature of healthcare delivery systems

The field of science and healthcare alongside the technology world is constantly evolving. Technology is improving the way in which we deliver and provide healthcare services and changing the face of healthcare from the digitalisation of healthcare records and referral pathways to robotic surgery, diagnostics, and treatment devices

(Han et al., 2019b). It is therefore important for healthcare workers to be trained efficiently in the use of technology for its full adaptation into the workplace. In addition, it is postulated that increased use of technology in healthcare will lead to more emphasis on the non-analytical, humanistic aspect of medicine due to the fact that immersive technology or artificial intelligence (AI) will play a larger role in the assistance of diagnosis and prognosis (Johnston, 2018).

1.5.3 Evolution of medical curriculum and a new generation of learners

There has been a shift in medical education from simple knowledge acquisition to a more rounded competency-based learner (Guze, 2015). Abraham Flexner, a renowned medical educator, is most noted for his report on medical education in 1910, which he presented to the Carnegie Foundation for Advancement of Teaching (CFAT). This report outlined the role of rote learning and memorisation and introduced the concept of alternative learning processes that engaged learners in more active and deeper learning processes. These processes were thought to nurture enhanced understanding, critical thinking skills and creative thought processes that can be supported by the intelligent use of educational technologies (Mishra, 2012). In addition, there has been a huge increase in the level of medical knowledge available, which has exponentially grown according to a paper published by Densen (2011) "*It is estimated that the doubling time for medical knowledge in 1950 was 50 years; in 1980, 7 years; and in 2010, 3.5 years. In 2020 it is projected to be 0.2 years- just 73 days*" (Densen, 2011). The growth in medical knowledge is also ably illustrated by the explosion of knowledge because of the global pandemic COVID-19 (Remtulla, 2020, Gordon et al., 2020, Ahmed et al., 2020).

In addition, there is an acknowledgement amongst medical educators that there is a new generation of medical students and future doctors who deal with different demands. Prensky (2001) famously termed the phrase *"digital natives*", which describes this new generation of learners. A digital native is learning in a different way compared to a 100 years ago; where they have grown up with technology, use it in every-day life and now expect to find it in the classroom and indeed the hospital (Prensky, 2001).

Furthermore, there has been a generational shift in adult learning theory. Locke's idea was centred around the idea that the mind was a blank slate where rote learning and memorisation was encouraged. This is in contrast to a new learner centred approach whereby the learner is the focus and is encouraged to learn through experience and practice. From an educator's perspective it is important to understand the fundamentals of how students learn, which in turn helps to develop effective teaching strategies. Medical schools use traditional didactic methods to teach students core knowledge from the syllabus (Dash et al., 2020, Schwartzstein and Roberts, 2017). In this teacher centred role students are considered passive learners. Interestingly students perceived traditional didactic lectures as the least effective teaching method, however if students are actively involved in the lecture it is regarded as a more effective learning tool (Butler, 1992). A well-established theme in medical education is the re focus from a teacher centred approach to a learner centred approach, which puts the emphasis on empowering the learner to develop lifelong learning skills (Kauffman and Mann, 2013). The teacher becomes a learner facilitator in this role which puts the emphasis on empowering the learner to develop lifelong learning skills (Kay and Kibble, 2016, Taylor and Hamdy, 2013). The theory behind this shift in our understanding of how students learn will be further discussed in the next section.

1.5.4 Economic factors

Educational technology has been used by educators throughout time to assist and support educational practices. However, immersive technologies have not been available for a long time due to high associated costs; though more recently the economic feasibility has been a game-changer for its implementation and use within medicine (Hamilton et al., 2021). While VR, AR, and MR use is in its infancy within medical education today, recent predictions on VR and AR technologies have suggested growth estimates from just over $12 billion in 2020 to $72.8 billion in 2024.

The International Data Corporation (IDC) Worldwide Augmented and Virtual Spending Guide predict rapid growth for the technology industry with a five-year compound annual growth for AR/VR spending will be 54% (Pears et al., 2020). The global pandemic COVID-19 has highlighted the benefit of immersive technology and has resulted in an increase in use of HMDs for educational and medical purposes. One example is of the use of AR headsets for telemedicine. In Canada, doctors located in a remote area in the province of Saskatchewan were able to consult with surgeons about patients who required wound reviews. Another example is a school in Kentucky, that used VR headsets (HTC VIVE) to teach classes during the pandemic (Singh et al., 2020). VR and AR have the potential to become a standard learning tool in education and could revolutionise the teaching and learning process via interaction with objects in 3D environments, while there is a strong demand in digital learning for the creation of multisensory digital learning ecosystems (Burke et al., 2017).

1.5.5 Advancement and advantages of technology

Educational technologies have evolved over the last century, from books to YouTube videos, to wearable headset devices and virtual worlds. A summary of the advantages of educational technologies for medical education include the following:

- A safe, controlled environment that eliminates risk to patient
- Enhanced realistic visualisation
- Authentic contexts for learning and assessment
- Documentation of learner behaviour and outcomes
- Instruction tailored to individual or group needs
- Learner control of the educational experience
- Repetition and deliberate practice
- Enhance perceptual variation
- Improved skill coordination
- Standardisation of instruction and assessment

As mentioned above, the amount of medical knowledge has increased exponentially over time. In the world of technology, Moore's law states that the number of transistors on a chip doubles every 24 months (Lundstrom and Alam, 2022). In broader terms this can refer to any technology that gets smaller, faster and cheaper exponentially over time. A comparison can be drawn from Moore's law in relation to the advancement of VR and AR technology, however the introduction of this technology is dependent on the appropriate research, availability, funding, and policy makers.

1.5.6 Side effects of immersive technology

Immersive technologies are not perfect, and one major limitation of their use is the side effects that the user may experience. Cybersickness is the most common self-limiting side effect experienced with the use of VR. Cybersickness may result in a variety of symptoms including nausea, disorientation, discomfort, headaches, fatigue, difficulty concentrating, and problems with vision (Servotte et al., 2020a, Rebenitsch and Owen, 2016). However, these symptoms are transient and lessen with VR experience. Previous studies have shown that these symptoms are not a barrier to the learning environment and that, with use, they lessen (Servotte et al., 2020a). However, there is very little published data in the field of medical education to date on this topic.

1.6 Learning theories

1.6.1 An overview of medical education

The “education of medical students” refers to the curriculum and educational practices that are implemented to teach and train medical students to become doctors, with the objective of becoming proficient in the skills and knowledge required to practice medicine competently. Medical education must prepare medical students to obtain a medical history, perform appropriate physical examinations, formulate diagnoses and management plans in addition to performing clinical tasks and undertaking professional responsibilities. This is coupled with the learning of how to appreciate and understand the art of medicine, and the basic sciences that are the foundation of care.

Medical graduates face a constantly evolving world, where their knowledge, skills and competencies are continuously challenged leading to a career of lifelong learning. Understanding how students learn helps educators to develop effective teaching

strategies. The way a student learns is an acquired trait or dependent on situational demands. Medical students are often required to adopt different approaches to learning depending on various elements of a course.

Three learning approaches are described in the literature: deep, strategic, and surface apathetic. The deep approach pertains to the idea of understanding concepts, relating, and having an interest in ideas. The strategic approach motivates students to be their best, achieving the highest scores. Characteristics of this approach include good time management and study organisation; however it can lead to fragmented learning and lack of understanding. Surface apathetic approach is characterised by rote memorisation, with a lack of understanding and a broad overview of the course material (Subasinghe and Wanniachchi, 2012). The literature suggests that deep and strategic learning approaches should be adopted by students as there is a positive correlation between the deep learning approach and quality of student learning (Trigwell and Prosser, 1991).

As part of a teacher's toolkit there are a variety of learning tools that can be used to facilitate learning. There are various forms of learning tools, including educational technology such as computers, iPads, books and simulation including VRLEs, which will be the focus of this thesis. VR technology has the capability to create meaningful learning experiences however, tools alone do not teach. Educators must develop VR learning tools using an instructional design process informed by relevant learning theories to make a successful VR learning tool that can assist in the learning process (Chen, 2010). This will facilitate the effective implementation and utilisation of VR

technology for educational purposes. Therefore it is important to understand the theory behind learning before the development of an educational virtual tool.

1.6.2 Learning theories

Learning theories describe ways in which knowledge, skills and attitudes are assimilated. It is important to understand and critically appraise the concepts and theories behind educational practices so educators can use them to inform and guide learning processes and develop learning tools (Kamel-ElSayed and Loftus, 2018). Without understanding the theory of learning there is a risk that innovative teaching may be misapplied with poor learning results or lead to repetition of previous teaching methods that may not be achieving any learning. Whether they are used in combination or stand-alone, they provide proven pedagogies for medical educators, especially in the development and use of educational technologies (Badyal and Singh, 2017).

Learning theories that underpin pedagogies within medical education relate to social, psychological, and philosophical theories (Taylor and Hamdy, 2013). The main learning theories include behaviourism, cognitivism, constructivism, social cognitive theory and humanism. Simulation based learning, specifically virtual reality, is grounded upon constructivism, Dewey's theory of experiential learning and elements of cognitive, social cognitive and behaviourist learning theories (Chen, 2010). I will discuss the following learning theories:

- Constructivist learning theory
- Experimental learning theory

1.6.2.1 Constructivist Learning Theory

The constructivist theory defines the learner as the maker of their own knowledge through the integration of learning activities and connecting experiences (Chen, 2010). Jean Piaget and John Dewey first explored the idea of constructivism, which was quite a shift in thinking from previous thinking on learning which was dominated by behaviourism (Taylor and Hamdy, 2013).

The theory of behaviourism is concerned with the learner's relationship between their environment and a stimulus. The focus is on observable increases, decreases or maintenance of behaviours. The theory of behaviourism is a teacher centred approach based on conditioning, for example positive reinforcement, negative reinforcement and punishment (Kay and Kibble, 2016). Before constructivism, it was presumed that there was a single point of view and that the mind is an empty vessel which could passively reproduce information that was presented. In contrast, constructivists believe that learners excel by engaging actively to construct knowledge in a learning-by-doing situation supported by prior knowledge (Kamel-ElSayed and Loftus, 2018). Several researchers discuss how constructivist learning theory and its various principles can be applied to the use of VR technology (Chen, 2010, Kay and Kibble, 2016). The principles of Constructivism are listed as follows:

- Learning brings individual prior knowledge, experience and beliefs to a situation
- Knowledge is constructed by the individual
- Learning is both an active and reflective process
- Learning is an organised process
- Learning is a social activity
- Learning is a self-regulated process

Learning brings individual prior knowledge, experience and beliefs to a situation

Constructivism requires a basis in prior knowledge in order to build and construct new knowledge, through assimilation and accommodation. This allows the learner to continue building upon old knowledge and assimilating new ideas or accommodate new information. Medical students use various study materials such as books and lectures to build a foundation of knowledge. VR technology can be used to build on this knowledge by creating a 3D environment to assist students in visualisation of anatomical structures or create 3D practical experiences e.g. surgical skills (Moro et al., 2017c).

Knowledge is constructed by the individual

As a simulation-based tool, VR provides a learning environment that allows learners to explore, manipulate and learn through experimentation without harm to the patient in real time (Cook, 2012). VR learning tools are self-directed and promote an active engagement by the learner to navigate the learning experience. This results in learners constructing their own knowledge in real time.

Learning is self-regulated process

Self-regulated learning through experiences is a core principle of constructivist theory. Learning is an innate process, which is personal and unique to the learner. This is an internal process that involves creating deeper learning processes that fosters change in mindset and understanding. In practice, self-directed learning encourages a deeper learning that promotes understanding, in contrast to rote learning and memorisation (Taylor and Hamdy, 2013). VR technology provides an individual learning experience

that allows for exploration and discovery of knowledge which the learner can create meaning from.

Learning is an organised process

The brain processes information and creates meaning through patterning. Effective teaching connects ideas and information in stages. VR provides a controlled environment, where learners can navigate and manipulate virtual objects by zooming in or out; move closer to an object or select an object to reveal more information, which can also be observed in real time. The concept of gaming introduces levels and the idea of building experience to advance and win a game. VR learning environments can be set at different levels i.e beginner or advanced level.

Learning is a social activity

Social interaction fosters a space to share multiple perspectives through collaboration, reflection and shared meaning. Medical education is a life-long learning experience, and a large part of learning is through individual and shared learning experiences. In addition to being a self-directed learning tool VR is versatile and can also facilitate shared learning experiences. VR can facilitate a shared space for a group of learners in the same setting or in a long-distance scenario (Burke et al., 2017). For example Second Life, a virtual world provides an online learning platform for healthcare professionals through case-based learning, clinical learning environments and team-based learning (Creutzfeldt et al., 2016).

1.6.2.2 Experiential Learning Theory

Experiential learning is characterised by learning by doing. This theory is based on the idea that the learner learns through experiences. John Dewey was an educational

theorist who developed the idea of learning through experience. Various definitions of this theory exist. For the purpose of this thesis I will use the following definition described by Kolb (1984):

> "Experiential learning is the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience". (Kolb et al., 2014)

This can be applied to VR technology as VR creates an environment that provides an experience (Schott and Marshall, 2018). David Kolb, an educational psychologist is known for his work on experiential learning theory. He developed a model of experiential learning based on his interpretation of the theory. The model is a four-stage cycle based on a series of steps illustrated in Figure 12 below. This theory can be applied to VR learning tools as follows. A VR learning tool involving a VR laparoscopic trainer for skill development is used as an example.

Concrete experience

VR provides an immersive environment that is both visual and auditory. It is dependent on the learners engagement with the activity to create a meaningful learning experience. For example VR laparoscopic trainers have been built for trainees to practice surgical skills (Lesch et al., 2020). The VR environment can immerse the learner in an operating theatre to practice laparoscopic skills and simulate a real-life experience.

Reflective observation

This step involves the learner reflecting on their experience personally. With VR technology, following completion of the learning experience the user should reflect on their experience and what they may have learned. As suggested by best practice guidelines on simulation, this should involve a session to facilitate feedback and discussion groups (Motola et al., 2013).

Abstract conceptualisation

In this step the learner forms new ideas or builds on previous experiences to create meaning. A VR laparoscopic trainer (a device used to train surgical trainees in minimally invasive surgical techniques) facilitates deliberate practice, where the learner can learn from their mistakes, practice steps of a procedure in a safe environment and without harm to patients. This leads to a development of skill and increases confidence levels with trainees (Araujo et al., 2016).

Active experimentation

The final step in the model is where the learner applies the new idea, new knowledge or new skill to the world around them. For example with a VR laparoscopic skills trainer, after practicing the skill they can apply it in the real world in surgery under supervision as the next stage of their training (Lesch et al., 2020).

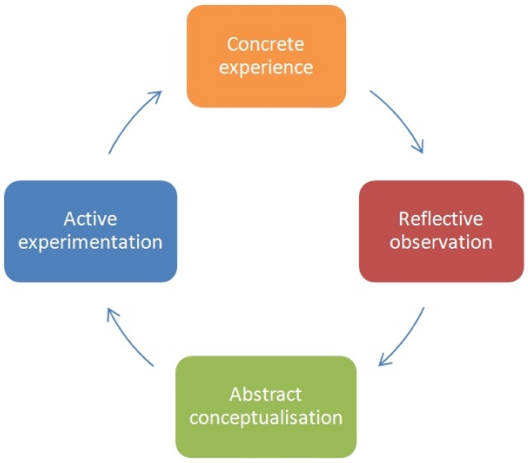


Figure 4 Kolb's Experiential Learning cycle (Kolb et al., 2014)

As the use of VR technology in education increases with its widespread availability and reduced costs, effective educational VR tools should apply learning theories including principles of constructivism and experiential learning to develop lesson plans and learning objectives for VR learning tools. This framework should also guide the instructional design phase of the educational VR tool, which will be discussed further below in this chapter (Motola et al., 2013).

1.6.3 Conceptual framework

How can we use learning theories to guide the development of educational virtual technology? A conceptual framework can be described as a guide for educators to create lessons for students to achieve prespecified learning objectives and is informed by learning theories, best practice or educational models (Bordage, 2009). Conceptual frameworks help clarify or identify a problem or learning goal and guide a path to possible solutions. Conceptual frameworks should guide the development of lesson plans utilising educational technology within the curriculum (Kyaw et al., 2019d).

Critical thinking and understanding allows educators to take ideas from various learning theories at different times for different learning approaches (Chen, 2010).

Even though research on the pedogeological basis for immersive technologies is still in its infancy, there has been extensive research carried out on learning theories and how conceptual frameworks should guide the use of computers and simulation in education, which can be applied to high-fidelity immersive technologies such as VR, AR, and MR (Car et al., 2019a). A conceptual framework can be developed by an educator, who can choose one or multiple learning theories and/or educational models in order to develop solutions to a learning problem or goal. Kerns approach to curriculum development is derived from the underlying assumptions that educational programmes have goals (Bordage, 2009). Kerns 6-step approach applies six various elements that help to identify the problem and arrive at a solution. The elements of the framework include the following:

- problem identification
- needs assessment of the learners
- educational goals and objectives
- instructional strategies
- implementation
- evaluation and feedback

There is a dearth of information on the learning theories and frameworks used to support virtual reality in medical education (Motola et al., 2013). A scoping review published in 2022 on the use of VR in medical education found that out of 114 included studies, three of those studies documented a framework or theory that they applied in

the development of VR simulators (Jiang et al., 2022). Few studies discuss the use of learning theories to develop conceptual frameworks for education technology. A study by Lorenzo-Alvarez investigated the design of a game-based lesson in Second Life, an online computer based virtual world to teach radiology to medical students. The study discussed how constructivism, cognitivism, and behaviourism inform how students learn in virtual worlds. Virtual worlds mimic real world scenarios where students can actively learn and apply information to their experience, thus constructing knowledge in real time. This demonstrates how principles of constructivism support VR learning tools. Furthermore, they can practise scenarios without patient safety concerns and apply their knowledge in real time compared to a passive learning experience (Lorenzo-Alvarez et al., 2018). Another study developed an augmented reality mobile app for general practitioners on the topic of antibiotic prescribing. The development of this AR app used a conceptual framework informed by the following learning theories: experiential, transformative and situational theory (Zhu et al., 2015). If VR educational tools are to be incorporated into the curriculum, their development should be guided by learning theories to ensure that they teach what they are supposed to teach. Further research on VR educational tools that are developed using an instructional framework guided by learning theories will provide an evidence base for its future use in medical education.

1.6.4 Instructional Design for educational virtual environments

Learning theories inform a conceptual framework that guides the development of a lesson. When the lesson pertains to using educational technology, specifically a VRLE, the next step of the overall educational framework is the instructional design element that involves the technical and practical aspects of building the VRLE. Again, there are few studies that report or use a guide or framework on the design of VR

learning tools. An instructional design comprises a set of practical steps to design effective instruction that helps learners in the learning process. Virtual Reality Instructional Design (VRID) is proposed by Chen as a development model for educational virtual environments and will be employed in this thesis (Chen, 2010). The model consists of four phases as follows and illustrated in Figure 13 below:

1. Define phase
2. Design phase
3. Development phase
4. Evaluation phase

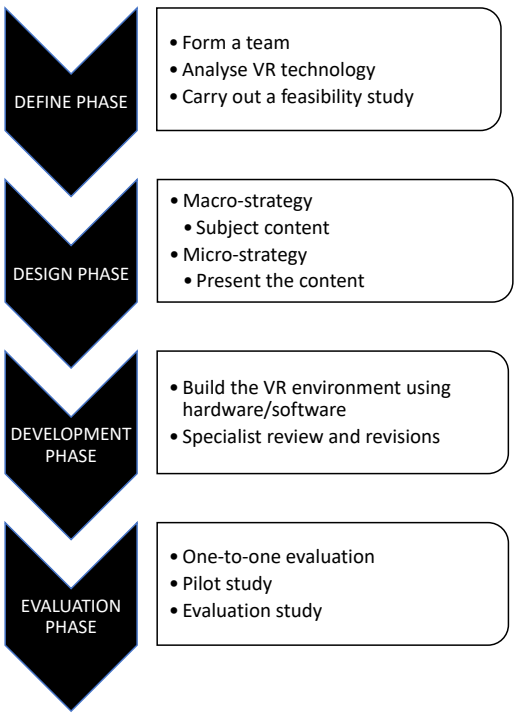


Figure 13 Four phases of VRID model

Define phase

The define phase involves three main duties including forming a team, analysing VR technology as a learning solution and carrying out a feasibility study.

Design phase

The design phase is comprised of two strategies: macro-strategy and micro-strategy. Macro-strategy refers to the subject content that needs to be presented. The presentation of the information including the organisation and sequencing is informed by different learning theories including principles from constructivist, cognitive theory, multimedia learning theory and the concept of integrative goals. Chen discusses how the concept of integrative goals provides a basis for identifying learning objectives. This is followed by identification and combination of the relationship between the VR objects to achieve the integrative goal. The concept of integrative goals is informed by behaviourist and cognitive learning principles such as attention, perception, motivation, and active learning. The learning objectives for the project “VR Baby” in this thesis will be discussed in the following chapters.

Moving onto micro-strategy, this is required to effectively present the learning content in a way that does not overload the learner. Mayer’s cognitive theory of multimedia learning presents the idea that deeper learning can occur when information is presented in both text and graphics rather than by text alone. This is an important theory to consider when developing educational tools that present information using multimedia (Mayer, 2005).

The theory proposes that there are two distinct channels in the human processing system. One channel takes visual or pictorial information and presents it for

processing, organising, and storage, while the second process does the same with auditory and verbal information. This theory is known as the dual channel theory of multimedia learning. However, this process depends on neither channel becoming overloaded with information, otherwise known as cognitive load. It is thought that there is a cognitive threshold within the brain and if it is overwhelmed with information there will be no learning (Hamilton et al., 2021, Mayer, 2005). This pertains to the usability of the VR environment, ease of use, ensuring the navigation is simple, self-intuitive and not burdensome for the learner. Further work by Mayer and colleagues led to the development of 12 design principles which were originally applied to written text and diagrams that were accompanied by verbal or recorded audio instructions (Çeken and Taşkın, 2022).

Over time, these principles have informed how information is presented in different learning environments. A systematic review was conducted to explore the principles of multimedia learning in different learning environments (Çeken and Taşkın, 2022). This looked at commonly used learning environments and how multimedia learning principles affect student learning. Results showed that out of 136 studies only five studies tested multimedia learning theory in a virtual learning environment and no studies tested the theory in an AR environment (Kartiko et al., 2010, Yahaya and Ahmad, 2017, Parong and Mayer, 2018, Makransky et al., 2019). The study notes that despite a lack of study focusing on multimedia learning principles in the AR and VR environments, there is still a tendency to use them (Akçayır and Akçayır, 2017, Garzón et al., 2019, Hamilton et al., 2021). As mentioned previously in this chapter and in this study, VR has been shown to positively impact learning outcomes and the learning experience (Akçayır and Akçayır, 2017). However the study identified a lack of investigation of multimedia learning theories in VR and AR learning environments,

which is required to ensure validity. Therefore, when developing a VRLE, multimedia learning theories should inform and guide the instructional design phase of development (Hamilton et al., 2021).

The next step in the design phase is review by specialist members from the participatory team including the instructional designer, interface design specialist and the subject matter specialist. This involves running through the design and revising accordingly as errors are highlighted and amendments need to be made.

Development phase

The development phase includes the technical aspects of progressing the design phase into a reality. The developmental platform i.e. the hardware and software is used to create a 3D interface and the educational activity or scenario based on the instructional design from the macro-strategy i.e. subject content of lesson. This is followed by a specialist evaluation which involves revising and identifying any issues that need to be revised. This cycle is repeated until the VR learning environment has reached an acceptable level.

Evaluation phase

One-to-one evaluation is where learners are asked to test the VR learning tool. This evaluation involves a debriefing session with the learner, troubleshooting any issues that may arise and an opportunity to provide feedback. Finally a formal process involving a small evaluation group (pilot study) and an effectiveness evaluation study (an experimental study involving a larger group to assess the effectiveness of the VR learning tool) should be carried out (Chen, 2010).

The existing literature demonstrate how experiential learning theory coupled with principles of constructivism are applied to the development of immersive educational technologies including VRLEs (Liaw et al., 2019a, Andersen et al., 2016). Bajpai (2019) discusses how learning theories are applied in immersive education research to guide conceptual frameworks that will help educators develop curricula, pedagogies, and assessments (Bajpai et al., 2019).

These theories have been applied to traditional education but are not being applied consistently in the development of immersive educational technology (Bajpai et al., 2019). A systematic review carried out by the Best Evidence Medical Education (BEME) collaboration characterised the features and uses of high-fidelity simulation. The review concluded that, under the right circumstances, with clearly defined conceptual frameworks and learning objectives, high-fidelity simulation, including immersive technologies, is an effective way for trainees to learn (Issenberg et al., 2005). This review outlines clear guidelines for educators to develop pedagogies for the use of simulation that can be adapted for VR educational tools to deliver effective education.

A recent review by Merchant (2014) also supports the importance of structuring a conceptual framework, identifying learning objectives and utilising an instructional design framework in the development of immersive learning environments (Merchant et al., 2014). The learning theories discussed above will inform the conceptual framework and guide the instructional design and development of the VR learning tool in this thesis. The conceptual framework and learning objectives will be outlined in further detail in chapter 3.

In summary, immersive educational technology, if well-designed, can encourage learners to take responsibility for their own education at the same time they are developing and applying skills necessary for their own learning (Han et al., 2019a). With immersive learning tools, students and healthcare staff are given an immersive interactive learning experience that allows for an enriched and safe learning environment for education and training purposes. This may prove very beneficial for emergency training, development of basic clinical skills, surgical skills, and for the increased understanding of complex concepts such as those found within anatomy, embryology, and physiology education (Dunleavy et al., 2019). Further evidence-based research is required to validate the effectiveness of these educational tools (Kyaw et al., 2019b).

1.7 Gaps in the literature

This comprehensive review has informed us on the types of immersive educational tools available, how and where they are being used within healthcare and medical education, in addition to identifying gaps in the literature. VR technology, specifically a VRLE, is a relatively novel and innovative tool. There has been a lot of research on VR tools in relation to anatomy education. As discussed in section 1.1.3.4, there are clear benefits of VR technology in teaching anatomy education, as it facilitates 3D visualisation of complex concepts. However, there is a paucity of evidence on the use of VRLEs to teach topics pertaining to the Obstetrics and Gynaecology undergraduate curriculum. In addition, there is a lack of theoretical underpinning in the development of VRLEs, with a call for an informed conceptual framework and design process when developing educational virtual technology. Furthermore, a lack of information on the costs associated and side-effect profile of VRLEs, may inhibit adoption into the

curriculum. There is a paucity of information on the exact costs and side effects of VR technology outlined in the literature to date. If VR technology is very costly and is associated with side effects, universities may be less likely to adopt the use of VR tools for education. Lastly, VR technology shows great potential for patient care and treatment; however, there are very few studies that research the use of VR technology in patient education, specifically within Obstetrics and Gynaecology.

1.8 Summary

In this chapter, I have presented an overview of simulation based medical education and the evolution of educational technologies in medical education. I went on to describe how learning theories underpin and inform pedagogies for immersive educational tools. There is an increasing amount of evidence in the literature that suggests immersive technology can provide knowledge gain, increased engagement and understanding during learning (Wang et al., 2020). In addition, it facilitates practice without the risk of human harm and helps to build professional skills and teamwork (Kyaw et al., 2019d). The potential for immersive technology to enhance healthcare education has been discernible for more than 40 years; however, it has not been available due to the associated high costs (Farra et al., 2019). With the widespread availability of more cost-efficient VR tools, they are becoming increasingly popular. However, further research is required to develop a firm evidence-based foundation for its implementation into the curriculum.

In this thesis I will employ a conceptual framework informed by principles from constructivism and experiential learning theories to guide the development of a VRLE. To structure the framework further, I will incorporate Kern's six-step approach to

curriculum development to address the learning problem and identify a solution and learning objectives (Robertson et al., 2019).

This evolution of how education is delivered and supported utilises concepts based on constructivism and experiential learning theory by which learners, "*use their experiences to actively construct understanding that makes sense to them rather than have understanding delivered to them in already organised form*". From the literature review above, educational virtual technologies are learning tools that are being increasingly used within medical education and can support students in their learning processes . To quote the famous Chinese philosopher Confucius: "*Tell me and I will forget, show me and I may remember, involve me and I will understand*" (Li and Li, 2019).

The focus of this thesis is VR educational technologies, more specifically VRLEs. There have been some studies in the literature that demonstrate the role of VRLEs for teaching and training in medical education (Alfalah et al., 2019). However, as outlined above there is a gap in the literature on the role of VRLEs in the area of Obstetrics and Gynaecology education.

Therefore, this thesis will begin by conducting a systematic review of the literature to assess the learning outcomes of immersive educational technologies, compared with traditional educational tools in healthcare education. Following this, I will describe the development our own VRLE, entitled "VR Baby" for Obstetrics and Gynaecology education and test it in a randomised control trial of medical student learning. I will apply a conceptual framework based on constructivism and experiential learning theory that will guide a lesson plan and learning objectives to address the difficulties of understanding complex anatomical and embryological relationships in Obstetrics

and Gynaecology education. The VRID model, as proposed by Chen (2010), supported by the conceptual framework and multimedia learning theory will guide the development of the VRLE. I will also use this VR learning tool to explore the role of the VRLE in midwifery education to enhance the understanding of complex topics, namely the relationship of the fetal head in relation to the pelvis. To complete the evaluation of the VRLE, I will present a cost analysis. Finally, I present a study, to investigate the role of a VRLE for patient education.

1.9 Aims and Hypothesis

This MD project endeavours to contribute to the growing body of research in educational technology. This thesis aims to explore the role of a VRLE in healthcare student education, with regard to knowledge acquisition and the learning experience via standardised assessment tools, coupled with investigating VR feasibility in relation to side effect profile and cost.

As discussed above, educational virtual technology is a growing field of research. VR technology is thought to be a useful learning tool that can support learning in various fields of medical education by creating an immersive, engaging, and safe learning environment. Within the domain of Obstetrics and Gynaecology education, there have been studies demonstrating the benefits of VR to teach pelvic anatomy (Hampton and Sung, 2010), ultrasound skills (Burden et al., 2013b), and gynaecology laparoscopic skills (Burden et al., 2013a). However, there is very little research on the use of VR to teach concepts relating to fetal development, and spatial relationships of the fetus to the pelvis. Furthermore, as outlined by AMEE and the Digital Health Collaboration, research to date is lacking in a theoretical framework to validate educational virtual tools, coupled with a lack of research on the learning experience associated with educational virtual reality tools (Kyaw et al., 2019d).

Therefore, the hypothesis of this thesis is that a VRLE is a novel useful learning tool that can improve knowledge levels and enhance the learning experience within the domain of Obstetrics and Gynaecology education at university healthcare education level.

1.10 Objectives of the Thesis

1. To evaluate the published data for the educational effectiveness of immersive technology.

   Study: In Chapter 2, I will conduct a systematic review to investigate the learning outcomes of immersive educational tools compared to traditional learning tools in medical, midwifery and nursing education.

2. To compare the effectiveness of a VRLE with a traditional PowerPoint tutorial for medical students learning on the topic: "*Stages of fetal development in pregnancy*".

   Study: In Chapter 3 I will describe the development of our own VRLE, "VR Baby" and use it as a platform for a 3D lesson on the topic of "*Stages of fetal development in pregnancy*". I will conduct a randomised controlled trial to investigate the educational effectiveness of "VR Baby", compared with a PowerPoint tutorial in a medical student population. Study outcomes will include knowledge gain in addition to an evaluation of the learner experience, including side effects of the learning experience with "VR Baby".

3. To evaluate the effectiveness of a VRLE in midwifery education on the topic of fetal lie, position and presentation in the third trimester.

   Study: In Chapter 4 I will develop a lesson on the topic of "*Fetal lie, position and presentation in the third trimester*" for our VRLE, "VR Baby" and carry out a mixed methods study, involving a pre- and post-assessment of midwifery students' knowledge and evaluation of the learning experience.

4. To evaluate the cost of implementing an immersive educational tool into the medical student curriculum.

   Study: In Chapter 5, a cost analysis will be carried out in accordance with national and international guidelines, based on the findings from the RCT from the perspective of the university.

5. To develop 3D models of congenital abnormalities and propose a future study for a patient case series exploring the role of VR for patient education, to enhance understanding and explore maternal-fetal attachment profiles**.**

   Study: In Chapter 6, I will develop 3D models of congenital abnormalities in the antenatal period for the purpose of patient education, including spina bifida, ventriculomegaly and congenital diaphragmatic hernia. I will carry out a pilot case study as proof of concept.

Chapter 2 Learning Outcomes of Immersive Technologies in Healthcare Student Education: A Systematic Review of the Literature

Manuscript accepted for publication with the Journal of Medical Internet Research: G Ryan, S Callaghan, AR Rafferty, M Higgins, E Mangina, F McAuliffe. Learning outcomes of immersive technologies in healthcare student education: A systematic review of the literature.

2.1 Summary

2.1.1 Objective

The objective of this review was to assess the effectiveness of immersive technologies, compared to traditional learning modalities, with regard to learning outcomes in medical, midwifery, and nursing student education.

2.1.2 Study Design

I conducted and reported a systematic review in accordance with Cochrane Collaboration guidelines and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis protocols (PRISMA-P). Randomised controlled trials (RCTs) were selected for review and the quality of evidence was assessed using the Medical Education Research Study Quality Instrument (MERSQI).

2.1.3 Results

Of 15,627 studies, 29 RCTs (N= 2722) were included and evaluated using the MERSQI tool. Knowledge gain was found to be equal when immersive technologies are compared to traditional learning modalities; however, the learning experience was increased with immersive technologies. The mean MERSQI score was 12.64. Immersive technology was predominantly used to teach clinical skills (15/29, 51%), and virtual reality (22/29, 76%) was the most commonly used form of immersive technology. Knowledge was the primary outcome in 28 studies (28/29, 97%). Nineteen studies (19/29, 66%) used validated instruments and scales to assess secondary learning outcomes including satisfaction, self-efficacy, engagement, and perceptions of the learning experience. Nineteen studies (19/29, 66%) included medical students (n= 1706), eight (8/29, 28%) included nursing students (n= 727), and two (2/29, 7%)

included both medical and nursing students (n= 289). There were no studies involving midwifery students. The studies were based on the following disciplines: anatomy, basic clinical skills and history taking skills, neurology, respiratory medicine, acute medicine, dermatology, communication skills, internal medicine and emergency medicine.

2.1.4 Conclusion

Our review suggests that when compared to traditional educational modalities, the learning gain from baseline is equal or increased with immersive technologies. Furthermore, learning outcomes such as student satisfaction, self-efficacy and engagement are all increased with the use of immersive technology, suggesting it is an optimal tool for education.

2.2 Introduction

Educational technology has been changing the way in which we learn for years. Its purpose is to ultimately support and improve education (Peterson and Mlynarczyk, 2016, Han et al., 2019a). To date, there has been a multitude of publications detailing the development and implementation of immersive tools and demonstrating the benefits of VR, AR and MR technology in medical, nursing and midwifery education(Maresky et al., 2019b, Moro et al., 2017b, Nicholson et al., 2006). This technology is thought to provide increased engagement and understanding during learning (Dunleavy et al., 2019). Additionally, it facilitates practice without the risk of human harm and also helps to build professional skills and teamwork (Samadbeik et al., 2018). More specifically within healthcare student education, the literature suggests that VR, AR, and MR can play an important role in anatomy education, basic clinical and surgical skills training, and also non-technical skills such as teamwork and communication skills. The Digital Health Collaboration carried out an extensive analysis evaluating the effectiveness of VR in healthcare professions education (Kyaw et al., 2019b). The study concluded that VR improved post-intervention knowledge levels and skills. However, it only included VR and both pre- and post- registered healthcare professionals. Further evidence is required on learning outcomes such as satisfaction, engagement and motivation, costing of immersive technology and the side-effects (Car et al., 2019b).

In relation to undergraduate education, there is a paucity of evidence in the literature on the learning outcomes, in addition to knowledge of these innovative educational tools. Hamilton (2021) looked at the pedagogical basis for immersive VR (I-VR) technology; most studies found a significant advantage of using I-VR, compared to

traditional methods. It also noted that there was a heavy reliance on knowledge outcomes as the primary method of assessment (Hamilton et al., 2021).

As evidenced from the literature discussed above, the vast majority of research in the literature also pertains to VR related technologies. This reflects that AR and MR technology related research is still very new. However, a recent systematic review on the state of AR applications in medical education identified 36 papers, divided into three main categories: namely surgery, anatomy, and other. They found that the quality of the studies were poor and lacking validity components. They did provide an analytical model for standardising the assessment of AR tools in an effort to guide future research in the area (Tang et al., 2020).

In order to further the evidence base for immersive technologies in medical education I sought to explore in more detail the learning outcomes of VR, AR, and MR technologies, in comparison to traditional teaching tools. Based on this, I developed two research questions: Are VR, AR, and MR as effective when compared to traditional teaching tools in delivering knowledge, as well as an enhanced learning experience? How are learning outcomes evaluated when using immersive technologies?

Therefore, the aim of this systematic review is to assess the learning outcomes of VR, AR, and MR across three healthcare student disciplines of medicine, nursing, and midwifery education, compared to traditional learning modalities. The learning outcomes include knowledge, skill development, and the learning perceptions of students, including satisfaction and self-confidence in learning, along with engagement and motivational factors.

2.3 Material and Methods

2.3.1 Purpose and protocol

I conducted a systematic review of the available scientific literature to assess the learning outcomes associated with the application of VR, AR, and MR as an educational tool, compared to traditional learning modalities for medical, nursing and midwifery students at (pre-clinical) university level, which included students studying at both undergraduate and graduate level education. A review protocol outlining the methods undertaken to carry out this systematic review was registered with PROSPERO in April 2020 (CRD42020154598) and is included in the appendices. This systematic review was reported according to the PRISMA-P (Moher et al., 2009) and the Cochrane Collaboration Guidelines (Page et al., 2021).

2.3.2 Eligibility criteria

I framed the research question based on Population-Intervention-Comparator-Outcome (PICO) criteria. This helped to define the research question, outline the eligibility criteria, and put a search strategy together. The population selected for this review included pre-clinical university students enrolled in three educational disciplines: medicine, nursing, or midwifery courses only. RCTs were included that implemented VR, AR, or MR technology in comparison to a control method. Due to the heterogeneity of definitions surrounding VR applications, I restricted inclusion to immersive forms of VR, including interactive games requiring a headset, virtual patients (VPs) or virtual reality learning environments (VRLEs) only. The primary outcomes included knowledge and reference to the learning experience that involved engagement, satisfaction, and perceived learning experience. Only studies published in English were included.

2.3.3 Search Strategy

A large-scale systematic search strategy was undertaken due to the wide use of the various terminology to describe VR, AR, and MR, and the technology surrounding their use in healthcare student education. The following method was used to identify empirical studies for inclusion in the systematic review. I conducted a comprehensive computerised database search of full-text articles published in English without any time restrictions. Only RCTs assessing learning outcomes using VR or AR or MR technologies, in comparison to traditional learning models were included. The reason for this is because I wanted to review the learning outcomes of immersive technologies, compared to traditional learning outcomes including knowledge and learner experience. As the fundamental study design of an RCT requires a control and an intervention group, these types of studies were therefore selected for this review. Searches were conducted with predefined search terms (Table 1), using the following electronic databases:

1. PubMed https://pubmed.ncbi.nlm.nih.gov/
2. EMBASE https://www.embase.com
3. Web of Science https://webofknowledge.com
4. CINHAL https://www.ebscohost.com
5. ERIC (Educational Resources Information Centre)
6. COCHRANE https://www.cochranelibrary.com/

In this review, there was no hand searching of journals or contacting of authors for unpublished research. This was mainly due to COVID-19, which resulted in closure of the university library. MESH terms were as follows: "*Virtual reality*", "*augmented reality*", "*educational technology*", "*imaging*", "*three dimensional*", "*education*" and

"*teaching materials*". Search terms were connected using Boolean operators 'AND' and 'OR' to capture all relevant article suggestions. The latest search was carried out on the 8th of March 2021.

Table 1 Comprehensive list of search terms developed for the search strategy

Discipline	Technology	Education	Academic
Medical	Virtual Reality	Teaching	Student
Medicine	Augmented Reality	Training	Trainee
Nurse	Mixed Reality	Lecture	
Nursing	Immersive Technology	Pedagogy	
Midwifery	Imaging	Education	
Midwifery	Three dimensional	Learning	
Midwives	Computer Simulation	Tutor	
	Information Technology	Lecturing	
	Educational Technology	Skill	
	High-fidelity Simulation Training		
	Technology		
	Simulation		
	User-computer Interface		
	Computer Simulation		
	Computer Assisted		

Table 1 Legend: The search terms included were divided into four categories: "*discipline*", "*technology*", "*education*", and "*academic*"

Databases were downloaded to ENDNOTE reference manager software (Endnote X8, Clarivate Analytics, Philadelphia), which recorded citations and identified duplicates. A spreadsheet was created simultaneously to record reviewer decisions and comments. Screening of articles was conducted by myself and a colleague in the research centre in an unblinded, standardised approach (independently and in parallel). Duplicates were removed first using ENDNOTE reference manager deduplication tool. After duplicates were removed, titles and abstracts of studies sourced through electronic databases were reviewed according to the inclusion and exclusion criteria described above. Subsequently, full texts of included articles from the initial screening process were reviewed for eligibility according to the described

inclusion and exclusion criteria. An article was excluded from the database if it failed to meet one or more of the following criteria:

1. **Study design**: If the publication was not an RCT, it was not included for further analysis. RCTs by definition include an intervention and control group. As the research question investigates the learning outcomes of VR, AR and MR compared to traditional learning tools, only RCTS were included for analysis.
2. **Intervention**: If the study intervention described was not an immersive VR tool that involved a VR headset OR Virtual Patient OR a VRLE, it was not included in the database for further analysis. During the preliminary search, VR is used very broadly to describe a multitude of learning tools some of which were not truly immersive such as three-dimensional (3D) printed models for example.
3. **Population**: If the study included qualified health care professionals, residents in training programmes or post-registered nurses and midwives or any other health care professional such as a physiotherapist or occupational therapist, they were not included in the study. The learning outcomes were reviewed in undergraduate healthcare students as they related to their training level. For example, including a study that tested a VR laparoscopic trainer in a population of novice learners and qualified doctors would alter the analysis on the learning outcomes as they pertain to a qualified healthcare professional where the learning outcomes are different. Therefore, it would be difficult to conclude any pedagogical evidence in the context of undergraduate healthcare education.
4. **Outcome**: If the learning outcome was not reported, the study was not included.

If there were any abstracts that were unclear and required full paper evaluation, they were included for full paper review. Full papers were sought for retrieval via PDF

format, hard copies which were obtained through contacting the library at University College Dublin (Gray et al.), ENDNOTE retrieval tools, searching the citation databases or google scholar). If an abstract or full paper was not available after all methods of search and retrieval were undertaken, then the resource was not considered for further review in the next step, after all full text articles were retrieved the articles were assessed for eligibility based on the aforementioned inclusion and exclusion criteria. Any differences of opinion were resolved by conversation between reviewers. A schematic step wise algorithm of the search strategy is demonstrated in Figure 14.

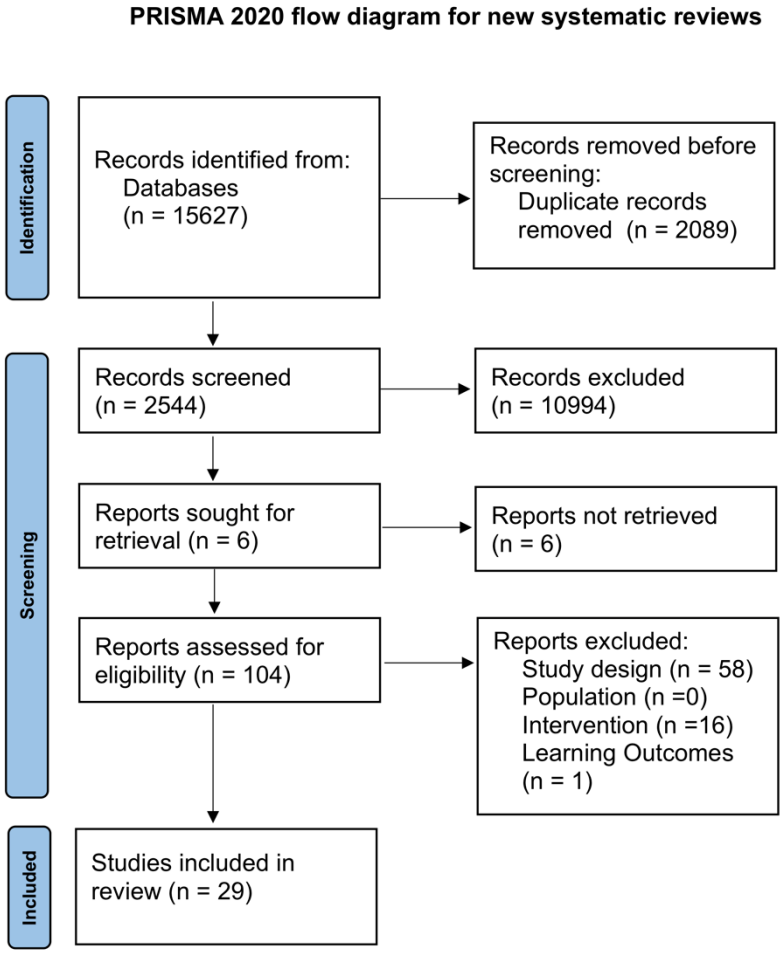


Figure 14 PRISMA 2020 flow diagram adapted for: Learning outcomes of Immersive Technologies in Healthcare Student Education: A systematic review

2.3.4 Data collection

Microsoft Excel (Microsoft 2020, Version 16.43) was used to build a data extraction form, which was divided into three categories: (1) study identification, (2) analysis of learning outcomes, and (3) study design. The first section included bibliographic information, country of origin of the study and a demographic description of the participants. The second section examined learning outcomes related to teaching

strategies, relationships between technology, and learning objectives. The third section evaluated the methodological quality of the study design.

2.3.4.1 Study Quality Assessment

To evaluate the study design, I used the MERSQI tool (Cook and Reed, 2015). The quality of clinical research is appraised using many different instruments, however there are only two instruments developed for medical education research, namely the Medical Education Research Study Quality instrument and the Newcastle-Ottawa Scale-Education. The MERSQI tool was implemented to assess the quality of research being undertaken, as it is thought that high levels of funding will increase the quality of research being undertaken. However Reed (2007), points out that there is no association between medical education research funding and the quality of studies. Therefore, developing an instrument to assess study quality would help determine justification for study funding allocation (Reed et al., 2007). I chose the MERSQI instrument, as it is applicable to medical education research and it has a structured and formal approach to assess methodological quality of research papers. It is divided into several domains, including evaluation of study design, sampling, data type, validity, data analysis, and outcomes (Cook and Reed, 2015). Learning outcomes are based on Kirkpatrick's hierarchy of educational outcomes, a four-level model that evaluates educational effectiveness (Atkins et al., 2009). The first level describes the participants' perception of the learning experience, whereas knowledge, skills, and attitudinal change are assessed in the second level, changes in behaviour are evaluated in the third level, with changes in healthcare or patient outcomes in the fourth.

2.3.4.2 Data analysis

A narrative review of results reported in the included studies on learning outcomes was carried out. Of note, the data in the final studies included for review did not allow for a formal meta-analysis, as studies were not sufficiently homogenous, given the research question stated and the use of different technologies and educational topics.

2.4 Results

2.4.1. Study selection

I identified 15,627 articles from the primary database search. After deduplication was performed in ENDNOTE, there were 13,538 articles left for abstract review. Abstracts were screened and 110 remained for full paper review. Six articles were not retrieved, and 75 articles were excluded, leaving 29 full papers for study inclusion. In total, 29 RCT studies (N=2722) were included in this review. All studies were carried out in the last 10 years, with the majority of studies published within the last 3 years (18/29, 62%).

2.4.2 Study designs

In total, 2,722 medical, midwifery or nursing students participated in the 29 RCTs. Among the articles, nineteen studies (19/29, 66%) included medical students (n=1706), (Seifert et al., 2020, Wang et al., 2020, Lombardi et al., 2014, Gnanasegaram et al., 2020, Moro et al., 2021, Stepan et al., 2017a, Hu et al., 2020, Kiesewetter et al., 2020, Schoeb et al., 2020, Noll et al., 2017, Ienghong et al., 2022, Sobocan et al., 2017b, Kockro et al., 2015, Nickel et al., 2016c, Nickel et al., 2016a, Bogomolova et al., 2019, O'Rourke et al., Du et al., 2020, Maresky et al., 2019b, Issleib et al., 2021), eight (8/29, 28%) included nursing students (n=727), (Menzel et al., Liaw

et al., 2019b, Liaw et al., 2020, Engum et al., 2003, Rossler et al., 2019b, Padilha et al., 2019b, Blanié et al., 2020, Liaw et al., 2014), and no studies involved midwifery students. Two studies (2/29, 7%) included both medical and nursing students (n=289) (Berg and Steinsbekk, 2021, Berg and Steinsbekk, 2020). The following disciplines of healthcare were used to test the immersive technologies: anatomy, basic clinical and history taking skills, neurology, respiratory medicine, acute medicine, dermatology, communication skills, internal medicine and emergency medicine. A full list of the RCT's, basic demographic details and immersive technology applications included in this review are outlined in Table 2.

Table 2 Randomised control trials included in this review of immersive educational tools

Author	Setting	Application Detail	Sample size	Purpose	Outcome
Seifert et al (2020)	Germany	Virtual Patient Cases (Moodle Learning Management System)	40	VP - basic clinical skills	Similar levels of long-term knowledge gained; Participants assessed learning experience and the comprehensibility of seminars as either "very good" or "good" (Seifert et al., 2020)
Wang et al (2020)	New Zealand	3D visualiser software (preloaded 3D hologram) on Microsoft HoloLens device	52	Anatomy teaching	There was no difference in knowledge acquisition between groups; only; MR group demonstrated higher retention in nominal and spatial type information; Increased engagement in 3DM and MR group (Wang et al., 2020)
Rossler et al (2018)	USA	VEST (Virtual Electrosurgery Skill Trainer - developed by National Institute of Health)	20	Fire safety knowledge	No differences in knowledge; intervention group participants were noted to meet performance criteria for their assigned role in their perioperative team (Rossler et al., 2019b)
Lombardi et al (2013)	USA	Virtual heart activities using physiology software programs (Practice Anatomy Lab, Pearson Education, and Interactive Physiology)	29	Anatomy teaching	Plastic model group achieved significantly higher overall scores on initial and follow-up exams; Attitude surveys demonstrated a higher preference for organ dissection (Lombardi et al., 2014)
Padilha et al (2019)	Portugal	Body Interact ™ (Simulation with virtual patients)	42	Respiratory Medicine	Knowledge improved in the intervention group and higher levels of learning satisfaction, No statistically significant differences in self-efficacy perceptions (Padilha et al., 2019b)
Liaw et al (2014)	Singapore	Virtual Patient Simulation - eRAPIDS (developed at National University of Singapore (NUS)	57	Clinical deterioration	No difference in acquisition knowledge; VP was rated positively (Liaw et al., 2014)

Author	Setting	Application Detail	Sample size	Purpose	Outcome
Menzel et al (2014)	USA	Second Life ® Virtual simulation environment (WALD Island)	51	Cultural attitudes	No statistically significant differences between learning format (Menzel et al., 2014b)
Gananasegaram et al (2020)	Canada	Campbells 3D Model on the inner ear- publicly available datasets displayed on HoloLens	29	Anatomy teaching	No difference in knowledge acquisition; HG group rated higher for overall effectiveness, ability to convey spatial relationships, and for learner engagement and motivation (Gnanasegaram et al., 2020)
Liaw et al (2019)	Singapore	Virtual Reality (No details)	198	VP to teach MDT rounds	Increased levels of self-efficacy and attitudes toward interprofessional team care (Liaw et al., 2019b)
Moro et al (2021)	Australia	Microsoft HoloLens; 3D studio Max (Autodesk Inc, San Rafael, California, USA), Unity 3D; Vuforia v5 plug-in for Unity (PTC Inc., Boston, MA) Samsung Galaxy Tab3 (Samsung Electronics, Seoul, South Korea); Visual Studio v2019	40	Physiology and anatomy of brain anatomy	No difference in knowledge test scores; Significant increase in dizziness using the HoloLens (Moro et al., 2021)
Stepan et al (2017)	USA	VR model of Brain anatomy - Brain CT's and MRI; Surgical Theatre (Cleveland, OH). Oculus Rift VR System, (LLC, Irvine, CA)	66	Cerebral Anatomy	No difference in anatomy knowledge; VR group found learning experience to be significantly more engaging, enjoyable, useful and more motivating (Stepan et al., 2017b)
Hu et al (2020)	Taiwan	Anatomy Master module of Medical Holodeck (Medical Holodeck, Switzerland)	101	Anatomy teaching	Significant improvement in ultrasound task performance, ultrasonographic image identification MCQ tests in the VR group (Hu et al., 2020)

Author	Setting	Application Detail	Sample size	Purpose	Outcome
Engum et al (2002)	USA	CathSim Intravenous Training System (CathSim) developed by HT Medical (Immersion)	93	Intravenous catheter training	Significant improvement in cognitive gains, student satisfaction and documentation of the procedure with the traditional laboratory group compared with the computer catheter simulator group (Engum et al., 2003)
Berg et al (2020)	Norway	VR application developed by the authors, with hired help for programming (Unity 2018.30f2), and video of the VR features	289	ABCDE Basic Resuscitation skills	Non-inferiority of learning modality; More students in VR group reported liking the way they practiced and that it was a good way to learn. VR group scored high on the System Usability Scale (Berg and Steinsbekk, 2020)
Kiesewetter et al (2020)	Germany	Virtual reality learning environment CASUS (http://www.casus.net)	142	VP to teach clinical skills	Case formats with a VP did not affect knowledge gain or diagnostic accuracy (Kiesewetter et al., 2020)
Schoeb et al (2020)	Germany	Instructions for catheterisation displayed on Microsoft HoloLens (Microsoft Corporation, Redmond, USA)	164	Catheter training	MR group had significantly better learning outcomes (Schoeb et al., 2020)
Noll et al (2017)	Germany	AR mobile app (iPhone operating system (iOS, apple Inc)-based app mArble Derma (m-ARBLE-dermatology)	44	Dermatological teaching	No difference in outcomes between groups (Noll et al., 2017)

Author	Setting	Application Detail	Sample size	Purpose	Outcome
Liaw et al (2020)	Singapore	3D Virtual Hospital developed – CREATIVE	120	Inter-professional skills training	No difference between groups in communication performance scores (Liaw et al., 2020)
Lenghong et al (2021)	Thailand	3D USS images played on downloaded phone app and AR	46	Emergency ultrasound skills	Better performance scores in VR flashcard group (Ienghong et al., 2021)
Sobocan et al (2016)	Slovenia	Virtual Patient - No detail	34	Internal medicine skills	No difference in exam performance between groups (Sobocan et al., 2017a)
Kockro et al (2015)	Switzerland	Virtual 3D model developed from MRI and CT scans and DextroBeam system (Bracco Advanced Medical Technologies, Princeton, USA	169	Neuroanatomy	There were no significant differences in knowledge scores; Participants rated the 3D method superior to 2D teaching methods in four domains: spatial understanding, application in future anatomy classes, effectiveness, enjoyableness (Kockro et al., 2015)
Nickel et al (2016)	Germany	Computer based TM developed using opensource Medical Imaging Interaction Toolkit software, developed by the German Cancer Research Center	410	Liver anatomy	3D group had higher scores and participants had a preference for 3D training (Nickel et al., 2016b)
Bogomolva et al (2019)	The Netherlands	DynamicAnatomy AR application developed at dept. of anatomy and embryology at Leiden University Medical Centre for innovation of Leiden University	60	Anatomy teaching	No significant differences in knowledge scores (Bogomolova et al., 2019)

Author	Setting	Application Detail	Sample size	Purpose	Outcome
O'Rourke et al (2020)	USA	VP model simulation developed with a real patient in real time	60	Clinical skill - breaking bad news	No significant between-group differences on the POMS 2 or salivary cortisol concentration following the SP interaction. Students have similar emotional and behavioural responses when delivering bad news to SP or vSP (O'Rourke et al.)
Du et al (2020)	Taiwan	3D models - Autodesk 3DS Max software (Autodesk Media and Entertainment, New York); Unity 3D and developed into a VR gaming system for HTC Vive	18	Anatomy teaching	No significant differences in MCQ scores between groups; VR groups scored highly on interest, competence, and importance subscales of IMI; Both VR groups considered the system to be fun and beneficial to their learning. MP group reported higher stress levels (Du et al., 2020)
Maresky et al (2019)	Canada	Using TeraRecon and Slicer; The Body VR: Anatomy Viewer Private Beta Version. Together with software provided by ShareCare VR	42	Cardiac anatomy	VR group scored higher on knowledge (Maresky et al., 2019a)
Issleib et al (2021)	Germany	VR software developed in cooperation between University of Hamburg and VIREED - VR-BLS course (using the Laerdal ® QPCR Mannequin)	160	Resuscitation training	Classic BLS training with a seminar and training sessions seems superior to VR in teaching technical skills (Issleib et al., 2021)

2.4.3 Study characteristics

Twenty-two articles (22/29, 76%) used VR applications, which included virtual simulation scenarios and VPs. Five articles (5/29, 17%) used AR applications, which involved using the Microsoft Holo lens headset and mobile phone applications. Two articles utilised MR (2/29, 6%).

Among the 29 articles retrieved, 28 (29/29, 97%) were from high income countries and one (1/29, 3%) was from an upper middle-income country. Most studies originated from the USA (6/29, 21%) and Germany (6/29, 21%), followed by Singapore (3/29, 10%), Canada (2/29, 6%), Norway (2/29, 6%), Taiwan (2/29, 7%), and one each from Australia, France, the Netherlands, New Zealand, Portugal, Slovenia, Switzerland, Thailand, and Turkey (1/29, 3% each).

2.4.4 Primary and secondary learning outcomes

Learning outcomes were reported in all studies, including outcomes on both knowledge and the participants' learning experience. Knowledge was assessed via multiple choice question tests (MCQs), single best answer (SBAs) tests, general clinical knowledge tests, open-ended style tests, or objective structured clinical assessment (OSCE). Of these, 12 studies (12/29, 41%) evaluated knowledge via MCQ tests. Nine studies (9/29, 31%) evaluated knowledge via general clinical knowledge-based tests which used a variety of validated questionnaires such as the Maastricht Assessment of Simulated Patient questionnaire and the Attitudes towards Poverty Scale questionnaire (O'Rourke et al., Menzel et al., 2014a). Three studies (3/29, 9%) assessed knowledge via open-ended style exam questions. One study (1/29, 3%) evaluated knowledge via an OSCE based exam. One study evaluated

knowledge via an SBA test, one study via interprofessional skills assessment and one study (1/29, 3%) did not specify the type of evaluation test.

Twenty-six studies (26/29, 90%) reported on satisfaction, attitudes, perceptions, opinions and general facts of the technology used. The learning experience was evaluated in various ways, including validated and non-validated instruments on satisfaction, engagement, and perceived learning outcomes. One study (1/29, 3%) used psychometric testing to evaluate the learning experience (Wang et al., 2020). Another study measured salivary cortisol levels pre- and post- intervention to evaluate whether delivering bad news via a real simulated patient or a virtual simulated patient evoked the same psychological stress (O'Rourke et al.). Nineteen studies (19/29, 66%) used validated scales to assess the learning experience including the Intrinsic Motivation Inventory (Du et al., 2020), General Self-Efficacy Scale, Learner Satisfaction with Simulation Scale (Padilha et al., 2019b) and the Diagnostic Thinking Inventory (Sobocan et al., 2017b). A full list of validated scales used in the RCT's in this review are found in Table 3. Two studies (2/29, 7%) reported on behaviours as an outcome (O'Rourke et al.), and no studies reported patient or healthcare outcomes. Only one study (1/29, 3%) reported on adverse health outcomes as part of their secondary outcomes (Moro et al., 2021).

Table 3 Validated scales used for evaluation

Validated scale	Study Title
Cambridge Brain Sciences psychometric tests (Wang et al., 2020)	A Randomised Control Trial and Comparative Analysis of Multi-Dimensional Learning Tools in Anatomy
Perioperative Performance evaluation tool (Rossler et al., 2019b)	Acquisition of Fire Safety Knowledge and Skills with Virtual Reality Simulation
Learner Satisfaction with Simulation; General self-efficacy scale (Padilha et al., 2019d)	Clinical Virtual Simulation in Nursing Education
Self-assessment of perceived learning (Blanié et al., 2020)	Comparative value of a simulation by gaming and a traditional teaching method to improve clinical reasoning skills necessary to detect patient deterioration: a randomized study in nursing students
E-learning system success scale (Liaw et al., 2014)	Comparison of virtual patient simulation with mannequin-based simulation for improving clinical performances in assessing and managing clinical deterioration: randomized controlled trial
Interprofessional Socialisation and valuing scale (ISVS) (Liaw et al., 2019b)	Finding the Right Blend of Technologically Enhanced Learning Environments: Randomized Controlled Study of the Effect of Instructional Sequences on Interprofessional Learning
Adverse health effects (Ames); Participant engagement (McBrien) (Moro et al., 2021)	HoloLens and mobile augmented reality in medical and health science education: A randomised controlled trial
Instructional Materials Motivation Survey (Stepan et al., 2017b)	Immersive virtual reality as a teaching tool for neuroanatomy
System Usability Scale (Berg and Steinsbekk, 2020)	Is individual practice in an immersive and interactive virtual reality application non-inferior to practicing with traditional equipment in learning systematic clinical observation? A randomized controlled trial
Cognitive load (Opfermann4-item scale) (Kiesewetter et al., 2020)	Learning clinical reasoning: how virtual patient case format and prior knowledge interact

Validated scale	Study Title
NASA task load index; Standard system usability scale (Schoeb et al., 2020)	Mixed reality for teaching catheter placement to medical students: a randomized single-blinded, prospective trial
POMS Questionnaire (emotional involvement); AttrakDiff2 Questionnaire (Noll et al., 2017)	Mobile Augmented Reality as a Feature for Self-Oriented, Blended Learning in Medicine: Randomized Controlled Trial
ATHCT; ISVS (Liaw et al., 2020)	Nurse-Physician Communication Team Training in Virtual Reality Versus Live Simulations: Randomized Controlled Trial on Team Communication and Teamwork Attitudes
Diagnostic Thinking Inventory (Sobocan et al., 2017b)	Problem-based learning in internal medicine: virtual patients or paper-based problems?
System Usability Scale (Berg and Steinsbekk, 2021)	The effect of self-practicing systematic clinical observations in a multiplayer, immersive, interactive virtual reality application versus physical equipment: a randomized controlled trial
Mental Rotation test (visual social ability) (Bogomolova et al., 2019)	The Effect of Stereoscopic Augmented Reality Visualization on Learning Anatomy and the Modifying Effect of Visual- Spatial Abilities: A Double-Center Randomized Controlled Trial
Profile of Moods States 2; Maastricht Assessment of Simulated patient (O'Rourke et al.)	The Emotional and Behavioural Impact of Delivering Bad News to Virtual versus Real Standardized Patients: A Pilot Study
Intrinsic Motivation Inventory (Du et al., 2020)	The impact of multi-person virtual reality competitive learning on anatomy education: a randomised controlled study
Comparative Self-assessment; System Usability scale (Issleib et al., 2021)	Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students: a randomized controlled trial

2.4.5 Study quality assessment

MERSQI scale scores ranged from 10-15, with a mean score of 12.64 (1.6). Table 4, below, demonstrates mean (standard deviation; SD) domain and item scores. Mean domain scores were highest for study design (1), data analysis (0.7), and outcomes (0.6). The lowest scoring domains included type of data (0.5), sampling (0.3) and validity of evaluation instrument (0.3). All 29 articles employed an RCT (100%) study design, which meant all studies obtained the highest score in this domain.

There was one double centre RCT (1/29, 3%) (Bogomolova et al., 2019), and the remaining 28 studies (28/29, 97%) were carried out at a single site. In relation to participant response rate, 27 studies (27/29, 93%) had a high response rate (>75%).

In relation to the validity of the evaluation instrument, 19 studies (19/29, 66%) used validated instruments and scales to assess learning outcomes including satisfaction, self-efficacy, engagement and perceptions of the learning experience.

Lastly, according to the classification using Kirkpatrick's criteria in the MERSQI scale, 28 (28/29, 97%) assessed knowledge as the primary outcome. Of these, 19 (19/29, 69%) used a pre- and post-learning experience knowledge assessment.

Table 4 MERSQI domain and item scores for 29 studies

Domain	*Item (Staudt et al.)*	*MERSQI Score*	*SD*	*Mean (domain)*	*SD (Domain)*	*N Studies*	*%*
Study design	1. Study design			1	0		
	Randomised controlled trial (3)	3	0			29	100
	Nonrandomised 2 group (2)	0	0			0	0
	Single group pre-test and post-test only (1)	0	0			0	0
Sampling	2. No. of institutions studied			0.3	0.15		
	3 institutions (1.5)	0	0			0	0
	2 institutions (1)	0.03	0.2			1	3
	1 institution (0.5)	0.48	0.1			28	97
	3. Response rate %						
	>75% (1.5)	1.4	0.4			27	93
	50-74% (1)	0.07	0.3			2	7
	<50% or not reported (0.5)	0	0			0	0
Type of data	4. type of data			0.5	0		
	Assessment by participants (1)	1	0			29	100
	Objective measurement (3)	0	0			0	0
Validity of evaluation instrument	5. Internal structure			0.3	0.27		
	Not reported (0)	0	0			12	41
	Reported (1)	0.59	0.5			17	59
	6. Content						
	Not reported (0)	0	0			11	38
	Reported (1)	0.62	0.5			18	62
	7. Relationships to other variables						
	Not reported (0)	0	0			20	69
	Reported (1)	0.31	0.5			9	31
Data analysis	8. Appropriateness of analysis			0.7	0.46		
	Appropriate for study design, type of data (1)	1	0			29	100
	Inappropriate for study design or type of data (0)	0	0			0	0
	9. Complexity of analysis						
	Beyond descriptive analysis (2)	1.31	1			19	65

Domain	*Item (Staudt et al.)*	*MERSQI Score*	*SD*	*Mean (domain)*	*SD (Domain)*	*N Studies*	*%*
	Descriptive analysis only (1)	0.34	0.5			10	34
Outcomes	10. Outcomes			0.6	0.21		
	Satisfaction, attitudes, perceptions, opinions, general facts (1)	0.9	0.3			26	90
	Knowledge, Skills (1.5)	1.45	0.3			28	97
	Behaviours (2)	0.14	0.5			2	7
	Patient/health care outcome (3)	0	0			0	0

2.5 Discussion

This systematic review addressed two research questions. Firstly, it assessed the current educational role of immersive technology in medical, midwifery and nursing education at university level compared with traditional learning modalities. Secondly, the review evaluated the associated learning outcomes of VR, AR, and MR and how they were evaluated. The main findings of this study indicate that knowledge gain is equal, when using VR, AR, or MR in healthcare student education compared to traditional learning modalities. In addition, VR, AR, and MR provide an enhanced learning experience based on the secondary outcomes of the studies included in this review (Maresky et al., 2019b, Padilha et al., 2019b, Wang et al., 2020, Liaw et al., 2014, Gnanasegaram et al., 2020, Stepan et al., 2017a, Moro et al., 2021, Berg and Steinsbekk, 2020).

All of the studies retrieved involved medical and nursing students in pre-clinical university education. Interestingly there were no studies involving midwifery students alone or in combination. Whilst there are studies involving midwifery students and immersive technologies in the literature, this review found no RCTs within this domain (Hardie et al., 2020, Agrawal et al., 2016, Williams et al., 2016). All studies were carried out in an upper-middle income or high-income country, which may be due to the availability of more funding to support the purchase of such equipment. Articles identified for this review were published within the last ten years with the majority (19/29, 66%) being published in the last three years. This highlights the recent rise in interest in immersive technologies for use in pre-clinical university medical and nursing education, coupled with the advancement of technology. Anatomy was the most common topic taught with immersive technologies, which may be due to the ability of immersive technologies to enhance understanding of complex body processes that

cannot be visualised. This study reflects similar findings within the literature, a recent systematic review also carried out exploring VR specifically in medical education, confirmed the effectiveness of VR in improving learners' level of anatomy knowledge (Zhao et al., 2020).

As discussed in Chapter 1, the use of 3D objects may enhance learning in subjects like anatomy and embryology education that require students to translate 2D images into 3D concepts (Brewer et al., 2012a). The findings of this review support this concept, in that the introduction of immersive technology as an educational tool could automatically standardise this process for students and enhance understanding of certain subjects like anatomy and embryology. VPs were developed in 12 of the studies (12/29, 41%) in this review. VPs play a key role in learning basic clinical skills for both nursing and medical education.

Traditionally, clinical education relies on practicing diagnostic, therapeutic and procedural skills on live patients. This can be difficult to balance on a day-to-day basis due to the fast-paced nature of medicine, time-constraints for clinical teaching in busy wards, and competition between students (McLaughlin et al., 2019). In addition, over the last year, the experience of the global COVID19 pandemic has vastly reduced the access to bedside teaching for both nursing, midwifery and medical students. Therefore, the availability and development of VPs and VRLEs can play a key role in the future as an adjunct to developing clinical skills to students at all levels and at any time (Pears et al., 2020).

The primary outcome in the majority of studies (28/29, 97%) was knowledge. Most of the studies reported no statistically significant changes in knowledge gain or reported similar levels of knowledge gained when compared to traditional learning modalities

(Table 2.2). Knowledge was assessed via multiple choice question tests (MCQs) (12/29, 41%), single best answer (SBAs) tests (1/29, 3%), general clinical knowledge tests (9/29, 31%), open-ended style tests (3/29, 9%), or objective structured clinical assessment (OSCE) (1/29, 3%).

In relation to secondary outcomes concerning the learning experience, all studies reported overall positivity and higher satisfaction in learning, self-efficacy, and engagement with immersive technologies. However, I noted that there is no universal standardised tool to evaluate the "*learning experience*" as it pertains to secondary outcomes such as satisfaction, self-confidence in learning, motivation, and engagement.

Moreover, this review revealed the heterogeneity of tools and instruments used to evaluate secondary learning outcomes. Several studies developed their own Likert-style assessment scales, whilst others used and adapted previously developed and validated scales for assessment of secondary learning outcomes. According to the Association of Medical Educators (AMEE), "*assessment tools selected should be valid, reliable, practical and have an appropriate impact on student learning*" (Shumway and Harden, 2003). Whilst this author acknowledges the difficulty in capturing the learning experience, perhaps this highlights the need for a standardised validated instrument to be designed specifically for immersive technology in education. For example, the National League of Nursing developed and validated a standardised scale to evaluate a simulation and student learning experience of the simulation activity including student's satisfaction and self-confidence, perceived learning and engagement (Padilha et al., 2019c).

Therefore, the development of a standardised instrument to evaluate learning outcomes, such as satisfaction, self-confidence, self-efficacy, and engagement for immersive educational tools may be beneficial so that future research may be better informed by a more uniform approach to assessing learning outcomes.

2.5.1 Strengths and limitations

A comprehensive search strategy and robust methodology support the strength of this study. Use of the validated MERSQI tool to assess the study design of the RCTs included also adds to the strength of the study design. Nevertheless, I recognise that there were also some limitations to the study. Common biases exist in the methodology section, including the study eligibility criteria, identification and selection of studies, data extraction and study appraisal. A predefined search criteria and inclusion criteria were set out in the published protocol which aimed to reduce these biases.

Within the published literature there is heterogeneity in how VR is defined, requiring us to confine VR to include use of a headset, giving an immersive experience only, as opposed to a 3D visualisation on a computer screen. Furthermore, due to the initial large database of articles retrieved, I decided to only include RCTs, as they included a comparator that was a traditional learning modality. Well-designed RCTs can provide a strong evidence base of a cause-effect relationship, and conversely poorly designed RCTs with flawed methodology can be dangerous as they may influence practice. The MERSQI tool enabled me to evaluate the quality of RCTs and distinguish between well-designed and poorly designed RCTs. During the study retrieval process, bias may have occurred due to the unavailability of some studies. Authors were contacted in cases of unavailable data; however this may lead to data availability bias

and unrepresented data. As this study included only pre-clinical university students, the value of immersive technology in the post-qualification setting is therefore unknown.

2.6 Conclusion

In conclusion, this systematic review demonstrates that immersive technology is equally effective in teaching compared to traditional modalities and increases learner satisfaction, self-confidence, and engagement. However, based on the low MERSQI scores found in this study, further research involving well designed studies is required to explore the role of VR, AR, and MR in medical and midwifery education.

Chapter 3 “VR Baby”, A virtual reality learning environment to assess the learning outcomes of medical students: A randomised controlled trial

Manuscript accepted for publication with IJGO International Journal of Gynaecology and Obstetrics: G Ryan, AR Rafferty, J Murphy, M Higgins, E Mangina, F McAuliffe. Virtual Reality Learning: A randomised control trial assessing medical student knowledge of fetal development.

3.1 Summary

3.1.1 Background

There is a lack of evidence in the literature on the learning experience of virtual reality learning environments (VRLEs) to facilitate learning within the specialty of Obstetrics and Gynaecology at university level education.

3.1.2 Objective

To compare student understanding of a complex Obstetrics and Gynaecology topic at two timepoints following a VRLE versus a traditional tutorial for university level medical students.

3.1.3 Study Design

I conducted a randomised controlled trial involving medical students from University College Dublin, Ireland. Participants were randomised to an intervention (VRLE involving a 15-minute learning experience on the stages of fetal development) or control (PowerPoint tutorial on the same topic) group. Multiple choice questionnaires (MCQ) assessed knowledge at three time points: pre intervention, immediately post intervention and one-week post intervention. Primary outcomes were differences in MCQ knowledge score differences post intervention between groups. Secondary outcomes included attitudes on the learning experience assessed using the Students Satisfaction and Self-Confidence in Learning Scale (SCLS) and the Virtual Reality Design Scale (VRDS).

3.1.4 Results

Data from 41 participants (n= 21 intervention and n=20 control group) were analysed. There was no significant difference in the primary outcomes of student understanding

and knowledge retention between the two groups (VRLE vs Traditional) (*P* = 0.91). Mean scores for satisfaction and self-confidence in learning were higher in the intervention (54.19 (7.54)), compared to the control group (50.45 (7.20), P = 0.21) however this was not statistically significant. Disorientation (48%) and dizziness (43%) were the most commonly reported side effects in the VRLE intervention group.

3.1.5 Conclusion

The VRLE did not improve student outcomes of knowledge when compared to a traditional didactic tutorial. VRLEs provide a positive learning experience associated with a high incidence and broad range of side-effects. This research bolsters existing research on VRLEs as a learning tool in medical education.

3.2 Introduction

A VRLE offers a promising opportunity to enhance understanding of 2D structures and physiological processes that can't be visualised. This is relevant to subjects like anatomy and embryology where students are required to translate two-dimensional (2D) images into 3D images, which can be quite a challenging cognitive leap for those who have difficulty visualising this transformation of images (Marsh et al., 2008b, Brewer et al., 2012b). This is potentially complicated further by students' subjective mental transformation of the 2D image into a 3D image, as they may mentally rotate these structures inaccurately, whereby the mind is filling in the gaps of any missing structures (Liesefeld et al., 2015). The introduction of immersive technologies could automatically standardise this process for students. Students can interact with the 3D object, zooming in, increasing the size, taking it apart and putting it back together. In addition to realising relationships to other anatomical structures (Marsh et al., 2008a, Brewer et al., 2012a, Liesefeld et al., 2015, Lo et al., 2019). In anatomy education, several studies demonstrated the value of 3D objects for increasing knowledge and understanding. A study which developed a 3D model of the inner ear and conducted an RCT with medical students showed an increase in knowledge supporting the educational effectiveness of VR (Nicholson et al., 2006). Kong (2016) demonstrated the use of 3D printing to successfully educate medical students about hepatic segments (Kong et al., 2016). Scores of the 3D model group were significantly higher, demonstrating it was superior to a textbook when learning pelvic anatomy. Further research is required to establish an evidence-base on the effectiveness of VR to enhance understanding of 3D structures in medical education (Kyaw et al., 2019b).

As discussed in Chapter 1, conceptual frameworks informed by learning theories can guide educators in the development of lesson plans utilising educational VR

technology. This provides effective VR learning tools that facilitates student learning to achieve a specified learning outcome e.g. knowledge. Constructivism and experiential learning theory are thought to inform how learning may occur with VR technology. VR technology facilitates a learning environment that creates an experience for the learner and an opportunity is provided for the learner to construct their own knowledge. Furthermore VR learning tools can be used individually or in a group setting. This fosters the idea that VR technology promotes self-regulated learning, a component of cognitive learning theory. In addition, this promotes a more learner-centred approach, moving away from a teacher-centred approach (Taylor and Hamdy, 2013). Until now there has been insufficient reporting or research on the use of conceptual frameworks to guide learning objectives and lesson plans for VR learning tools. Best practice guidelines encourage the reporting of conceptual frameworks to support the educational effectiveness of VR learning tools (Motola et al., 2013).

Instructional design combines the conceptual framework and learning objectives serving as a blueprint to develop VR learning tools. Several systematic reviews, including a Cochrane review have commented on the abundance of new VR learning tools that are being developed however they conclude that there is very little evidence or reporting of instructional design to support the educational benefit of VR technology (Zeiger et al., 2017, Abboudi et al., 2013, Khan et al., 2019, Kyaw et al., 2019d, Car et al., 2019a).

In Obstetrics and Gynaecology education, VR has been used to help students learn about female pelvic anatomy, enhancing 3D understanding of structures which can be difficult for medical students (Hampton and Sung, 2010), in addition to ultrasound

training and laparoscopic skills for gynaecological procedures (Burden et al., 2013c, Ebert and Tutschek, 2019, Ko et al., 2018). More specifically, in embryology, medical students often struggle to grasp complex “invisible concepts”, such as stages of fetal development during pregnancy (Popovici et al., 2017a). Few studies have been published investigating the role of VR technologies to facilitate learning embryology. Two recent studies both developed VRLEs to facilitate learning embryology; however, neither study reported on instructional design and no evaluation was carried out to assess the educational effectiveness of these tools (Popovici et al., 2017b, Abid et al., 2010). There is a paucity of information relating to its effectiveness, specifically the learning objectives of VR technologies as demonstrated in our systematic review and in the published literature (Kyaw et al., 2019b).

In this study we develop a VR learning tool based on the VRID model proposed by Chen to facilitate learning of pre-specified learning objectives outlined below in the methodology. This is followed by an RCT to compare the effectiveness of a VRLE with a traditional PowerPoint tutorial for medical students learning on the topic: “*Stages of fetal development in pregnancy*”.

3.3 Methods and Materials

3.3.1 Study Design

I conducted a prospective, non-blinded, RCT. The study was non-blinded, as I the researcher was running the trial. Students who had completed the embryology module, from the undergraduate (six-year programme) and graduate-entry (four-year programme) medical degree programmes at University College Dublin were invited to take part in the study. The study took place between July and November 2020 during the global pandemic COVID-19.

3.3.2 Ethical approval

Ethics permission was firstly obtained from the Research Ethics Committee at the National Maternity Hospital (Reference No: EC23.2019) on the 26th of November 2019. To collect ultrasound and MRI scans, from women attending the National Maternity Hospital for their antenatal care, in order to develop 3D objects for the VRLE. Secondly, ethical approval for the RCT was granted by the University College Dublin Research Ethics Committee (Reference: LS-20-09-McAuliffe) on the 26th May 2020 and registered with the ISRCTN trial registry (ISRCTN No. 19845486 https://doi.org/10.1186/ISRCTN19845486). The ethics approval letters and study protocol for the RCT can be found in the appendices.

3.3.3 Participant Recruitment

Students studying in the undergraduate (6-year programme) or postgraduate (4-year programme) medical degree programme at University College Dublin were invited to participate. Students were invited via announcements on Brightspace (the university e-learning platform), class announcements, and medical student societies. Interested

students contacted the study team via the email address provided and were sent an information leaflet and consent form to review. The information and consent form are included in the appendices. Consent forms were signed electronically to reduce physical contact, in line with COVID-19 guidance.

3.3.4 Inclusion and exclusion criteria

All medical students, except those under the age of 18, non-English speaking, or with a medical condition including cardiac (e.g., pacemakers) and binocular vision abnormalities, psychiatric disorders or epilepsy, were eligible to take part in the study. All participants met the inclusion criteria, and no participants were excluded from the study. Participating students had completed the standard curriculum embryology module on the stages of development of the fetus.

3.3.5 Participant Randomisation

Figure 15 depicts the randomisation and allocation process for the study. Eighty-eight students emailed to express interest in the study and were sent the information leaflet and consent form to review. Fifty-six students responded with completed and signed consent forms, and 32 students did not respond further. Student university numbers were recorded, and each student was assigned a study identification number in order to pseudo anonymise participation and results. Participating students were then randomly allocated on a 1:1 basis to either an intervention (VRLE involving a 15-minute learning experience on the stages of fetal development) or control (traditional tutorial on the same topic) group. The researcher (GR) conducting the investigations was not blinded to participant or study group allocation, given the nature of the study design.

CONSORT
TRANSPARENT REPORTING of TRIALS

CONSORT 2010 Flow Diagram

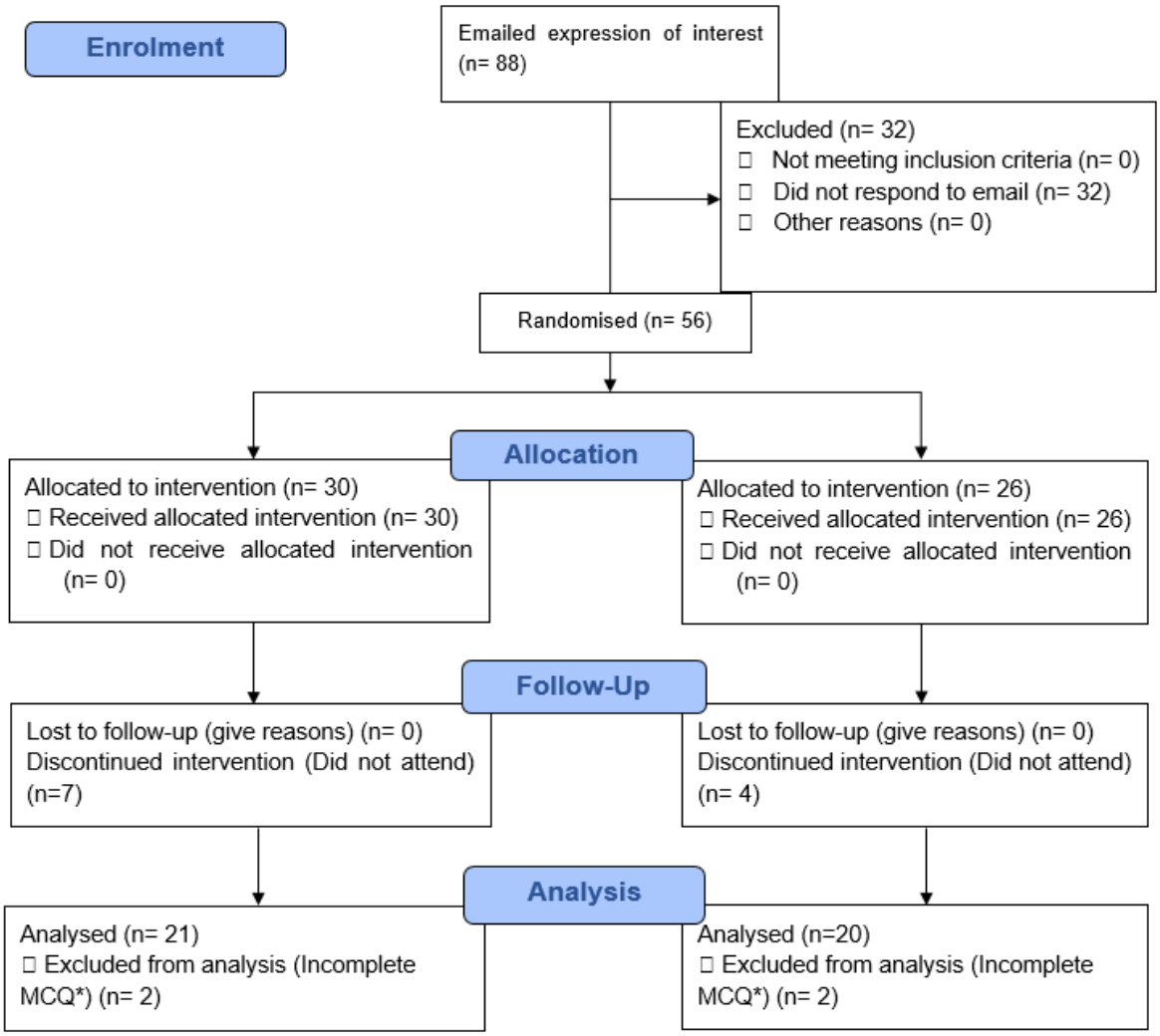


Figure 15 CONSORT Diagram representing the randomisation process

***MCQ: Multiple Choice Questions**

3.3.6 Sample size

The sample size was calculated in conjunction with advice from the university statistical support group (CSTAR), based on previous similar studies in the literature (Table 5). Assuming a normal distribution, with a standard deviation of 1.75 taken from literature (Nicholson et al., 2006), the sample required to demonstrate a difference of two between the intervention and the control groups at a type I error rate of 0.05 (adjusted for multiple comparisons) at 90% power with an allocation ratio of 1:1. After an adjustment to allow for 20% drop-out, the total sample size required was 40 for 90% power.

Table 5 Power analysis for sample size

	Sample Size per group		**Total sample size**	
	Power = 80%	*Power = 90%*	*Power = 80%*	*Power = 90%*
Difference = 2 (Staudt et al.)	13	17	26	34

3.3.7 VRLE Intervention

3.3.7.1 VRLE Development

The intervention involved the development of a lesson in the form of an immersive VRLE, which was created to explore the stages of fetal development during pregnancy. The VRLE was designed in collaboration with the UCD Computer Science Department using a combination of online tutorials and documentation in the literature regarding VRLE development (Allen et al., 2016b, Chang et al., 2017, Werner et al., 2017).

3.3.7.2 Theoretical framework

The conceptual framework of the VR learning tool is informed by principles of constructivism and experiential learning theory. The idea of learning with VR is thought to encourage an immersive learning experience that stimulates attention, perception, motivation and an active learning experience. The integrative goals of VR combines the conceptual framework and are aligned to the learning objectives. To further structure the lesson I have employed Kerns six-step approach to curriculum development (Table 6) (Robertson et al., 2019). The learning objectives of the VR learning tool are as follows:

- Facilitate a learning experience
- Knowledge gain on the topic of stages of fetal development in pregnancy
    - Fetal development in the 1st trimester
    - Fetal development in the 2nd trimester
    - Fetal development in the 3rd trimester
    - Fetal developmental abnormalities
    - Technical aspects of fetal development i.e measuring fetal growth

    - Placental function
- Enhance understanding of 2D images of fetal development in pregnancy by converting them into 3D in a VRLE
- Increase learner self-confidence and satisfaction with study material

Table 6 Application of Kerns 6-Step approach for VRLE development

Problem Identification	Understanding spatial relationships within Obstetrics and Gynaecology education
Needs assessment of the learners	Poor understanding of spatial relationships of the fetus and the pelvis during development and labour
Educational goals and objectives	Knowledge of fetal development and anatomical relationship to the pelvis in pregnancy for clinical application in practice
Instructional strategies	Gamification - VR learning tool for 3D visualisation Learning can be fun and engaging
Implementation	Virtual reality learning environment – educational game for medical students
Evaluation and feedback	Knowledge MCQ pre- and post-lesson Learning experience questionnaire

Table 6 Application of Kern's Six-Step approach in the lesson development of a VRLE for 3D visualisation of fetal development and fetal positions in pregnancy.

The design element of the VRLE is guided by the VRID model, an instructional design framework developed by Chen (2013). This model focuses on the content development for the VRLE and helps to structure and guide the team involved in the developmental role (Chen, 2010).

As previously outlined in Chapter 1, section 1.6.4, the instructional framework is comprised of four main components; define phase, design phase, development phase and evaluation phase. The define phase involved forming a participatory team; analysis of the appropriateness of employing VR to tackle a learning problem and carrying out a feasibility study. The team included a manager (FMcA), a subject matter specialist (FMcA/MH/GR), instructional design specialist (EM/JM), interface design specialist (EM/GR), technical specialist (EM/JM), potential learners (medical students). The computer Science team constructed the VRLE using specialised computer technology. I gathered information from other studies that developed VR tools for medical education to help guide the development of our VRLE. I worked with the computer science team throughout the design process, checking the subject content of the design at each step, addressing any design issues and troubleshooting i.e anatomical appearance of 3D objects. In a step wise manner, the team worked together throughout the design and development process.

The design of the VRLE involved several meetings to discuss the idea of what the VRLE will look like and how the participant uses it. Principles of constructivism and experiential learning theory coupled with multimedia learning theory are applied throughout the development process. The VRLE creates a learning experience as the learning material is presented in 3D format with visual and auditory information i.e 3D designs of the developing fetus during pregnancy. A game-like lesson was developed,

where participants had to find the information to complete the MCQ at the end of the lesson. This provided motivation to engage with the VRLE. Prior anatomy and embryology knowledge meant that the user could build on previous knowledge to develop further understanding of the topic. Visual images in 3D are accompanied by text boxes when the student clicks on the object in the VRLE. Presenting information in this way is thought to enhance learning and reduce the risk of cognitive overload, based on Mayer's cognitive theory of multimedia learning (Mayer, 2005).

I had several roles in the development of the VRLE, I assisted in designing the lesson plan and setting the learning objectives. As part of my role on the team I designed the lesson in 2D with drawings and images of the lesson. The technical specialist built the lesson in 3D using his background in computer science technology. At each step of the development the team met to discuss the progress, which provided an opportunity for feedback or troubleshoot any issues. The subject matter specialists' (FMcA/GR) knowledge of obstetrics and gynaecology helped to develop the VRLE.

I hypothesise that the area of Obstetrics and Gynaecology has a unique need for immersive technologies to enhance learning and understanding. Medical students are required to complete a six-week module in Obstetrics and Gynaecology as part of their clinical rotations, during their final two-years of the undergraduate or graduate-entry medical programme at University College Dublin.

Student feedback provided a valuable insight into the requirements of students when they undertake their Obstetrics and Gynaecology rotation. This is carried out via formal surveys following the end of the module and allows the students an opportunity to comment anonymously on what they thought of the module. This allows the department to reflect on their teaching and the content of the module. In this way,

future rotations can be modified or amended to in terms of module content or methods of teaching. Students often struggle at the beginning of the placement with regard to trying to remember basic anatomy and embryology essential for understanding the development of the fetus during pregnancy, as they would have undertaken anatomy and embryology modules in their first two-years of the programme. With that in mind, and as this was the first attempt at developing a resource tool for Obstetrics and Gynaecology education, I decided to develop a simple lesson on the topic of "*Stages of fetal development during pregnancy*".

The development process was as follows. Firstly, I attempted to develop 3D models of the fetus at each developmental stage of the pregnancy using a combination of ultrasound and MRI scans obtained with consent from women attending for antenatal care at the National Maternity Hospital. After an initial attempt to convert the ultrasound and MRI images into 3D, we realised that we were limited by experience, time, and the image quality. We were able to convert an MRI scan into a 3D image of a fetus (see Figure 16). However, to develop the lesson further I required more skill and expertise to use the software and manipulate the images to make a full interactive lesson.

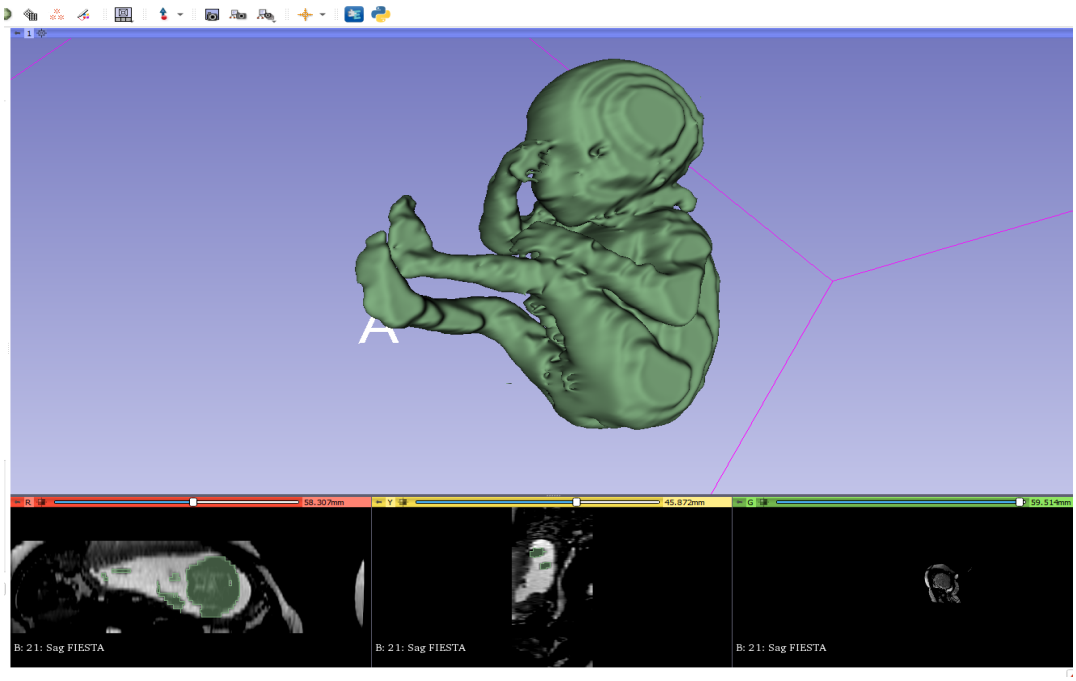


Figure 16 Fetal MRI data converted into a 3D model in 3D Slicer software

Another limitation was the quality of the fetal MRI scans. An MRI scan images the body in a process that subdivides a section of the body into a set of slices and then each slice is cut into rows and columns to form a matrix of individual tissue data points, also known as a voxel, to form an image. Thinner slices produce better quality images. In the fetal MRIs collected for this study, the slices were too large, resulting in poor quality image development. The moving fetus during the MRI scan also contributed to poor image quality. From the research carried out, other studies use CT scan images, which are programmed to take thinner “slices”, in addition to a patient that can stay relatively still during the scan. This results in better quality images; therefore these types of scans are better suited for conversion into 3D. Moving forward with our study, we decided to carry out an online search of opensource STL files of fetal models, which I found on CGTrader (https://www.cgtrader.com/). Basic stereolithography (3D image files) were obtained from CGTrader and used in combination with 2D fetal ultrasound and MRI images from the hospital database images. The technical specialist from the UCD School of Computer Science used various computer programmes as follows to build the VRLE.

At each design phase including the macro and micro strategies, I met with the technical specialist to review the images and make any changes necessary. These changes included clarifying and differentiating between anatomical parts and artefact. Any conflicts were resolved by subject matter specialist (FMcA). Blender (version 2.91.2), an opensource computer graphics software programme for the creation of virtual environments and scenarios for computer-aided applications (Govea-Valladares et al., 2018), was used in tandem with Unity 3D (version 2020.2.1) to create 3D images compatible with an Oculus Quest head mounted display (HMD) and controllers (Figure 17, Figure 18).

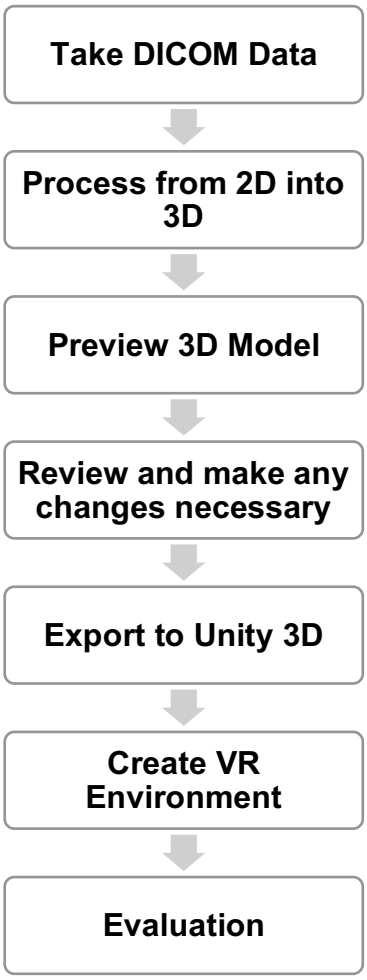


Figure 17 Flowchart diagram of the DICOM images converted into 3D models using opensource software

HMD placement and the images seen by the participants are shown in Figure 19 to 23. Additionally, 2D ultrasound and MRI images of the fetus at different developmental stages were included in the VRLE for clinical correlation, which are illustrated specifically in Figure 20 and 21.

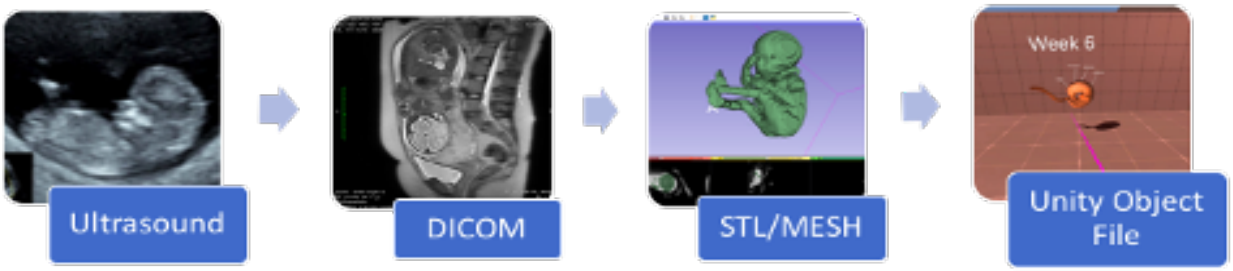


Figure 18 Flowchart of image conversion process of 2D ultrasound and MRI DICIM images into 3D images in Unity software

Expert validation by Obstetrics and Gynaecology professionals was sought throughout the development process to ensure medically correct reconstruction of the 3D learning objects and their implementation into the VRLE. This process was repeated during each phase until satisfactory results were achieved. Due to COVID-19 and public health restrictions we conducted a small feasibility study before conducting the RCT with 2 medical students. The 2 students were given instructions on how to use the headset and how to navigate inside the VRLE. The feedback from the students pertained to design elements, and the resizing of certain images and text bubbles. We also tested the VRLE in the room to determine how much space we would need and how to conduct the study in a safe way i.e., under COVID-19 circumstances. We also tested running the VRLE while standing up or sitting down. If a student felt dizzy, they could have the option of sitting down during the VRLE. Overall, they felt it was self-intuitive and found it easy to navigate. This helped to support the face validity of the learning tool. As this study took place during the pandemic, the learning experience was carried out under government and public health directed protocol and guidance in relation to COVID-19. This included appropriate hand and respiratory hygiene, with facemasks and social distancing of two metres, where possible (unless help was

required to adjust or take off the VR headset). Extra masks and hand sanitiser were always supplied and available during study participation.

The last step of the design process was the evaluation phase. Participants were given a short introduction on the use of the VR headset and controls, including how to put on the headset and how to navigate the hand controllers, and were then instructed to use the headset for 15-minutes. The intervention lasted approximately 30 minutes in total.

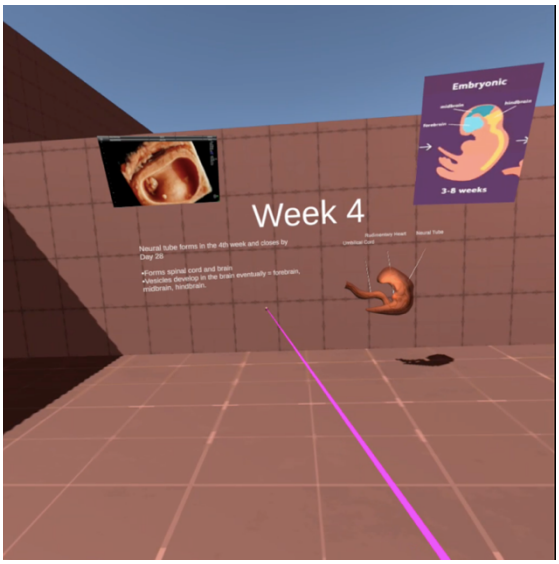


Figure 19 Image of VRLE "Stages of Fetal Development" at week 4 weeks' gestation

The interactive VRLE involved a "treasure hunt" for information, linking images to key learning points relating to fetal development. Using the controllers, participants could select internal organs on the fetal images being visualised in the HMD that were relevant to the stage of development. Doing so revealed learning points necessary for knowledge assessment after the VRLE experience. The bespoke designed VRLE was given the name of "VR Baby".

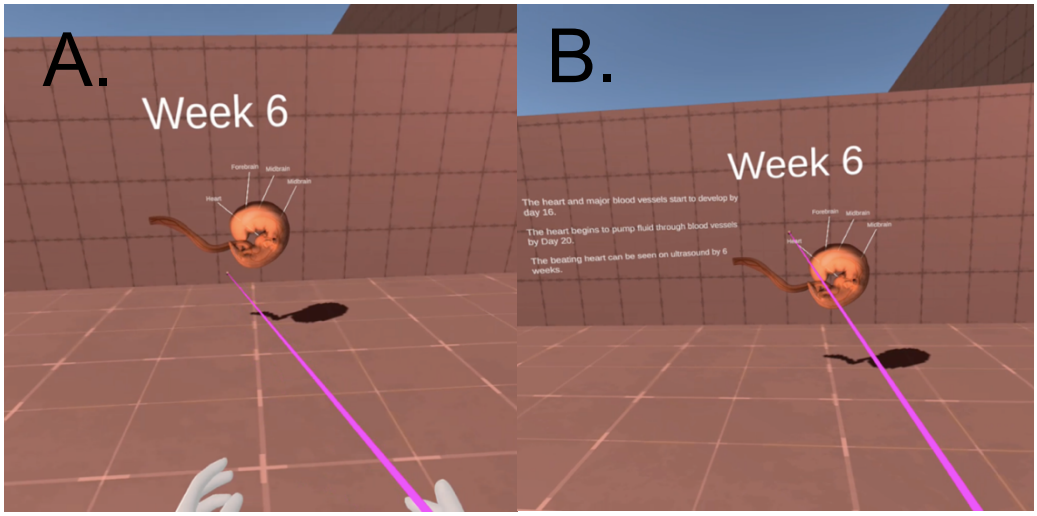


Figure 20 A: basic image of "VR Baby" showing the fetus at 6 weeks gestation; B: Information appears once the fetus is selected "clicked"

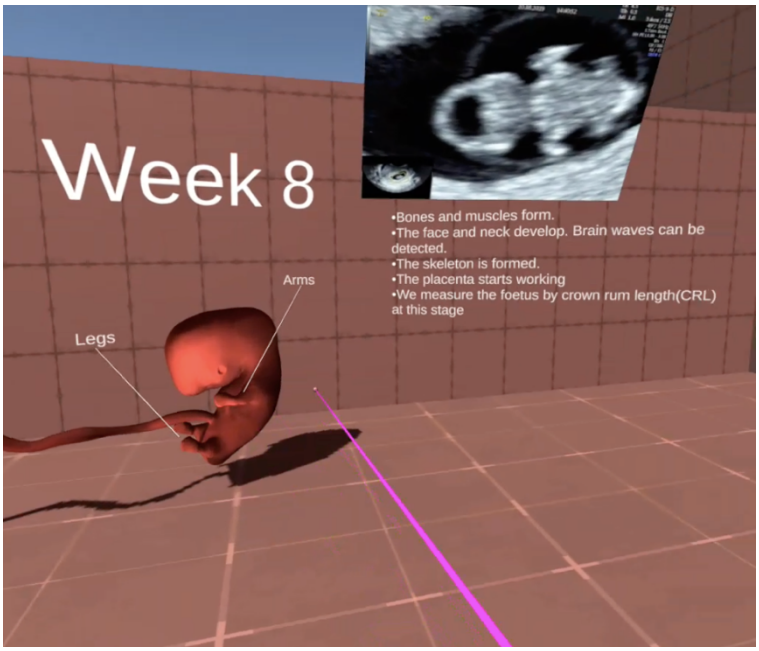


Figure 21 Image of fetus at 8 weeks gestation demonstrating a 2D ultrasound image for clinical correlation

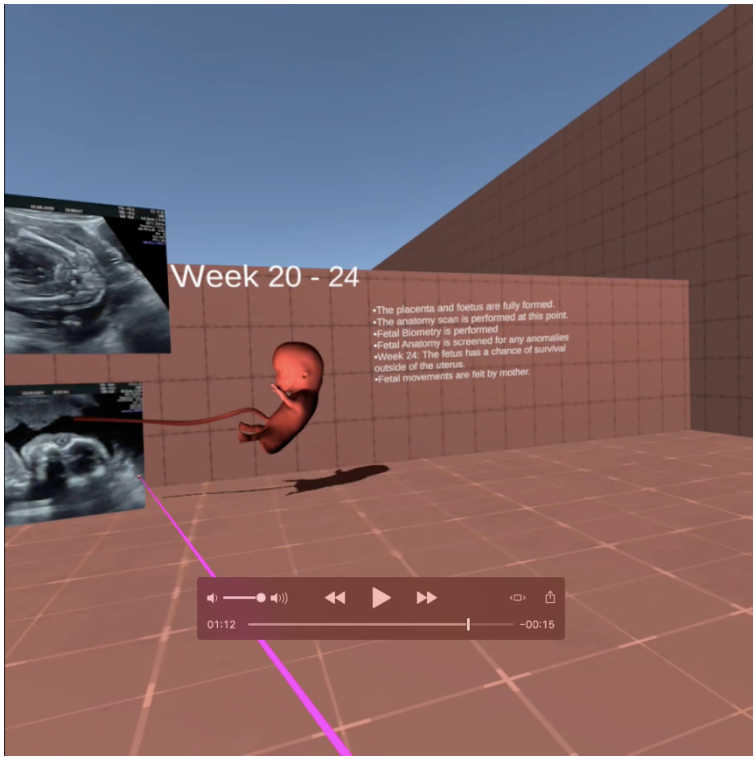


Figure 22 VRLE Headset view of fetal development at 24 weeks' gestation



Figure 23 Images of participants wearing the Oculus Quest headset undertaking the VRLE intervention (taken with permission)

3.3.8 Traditional Tutorial

The control group underwent a traditional learning experience consisting of a face-to-face teaching tutorial on the topic stages of fetal development in pregnancy. Due to COVID-19 restrictions, the tutorial was conducted via an online video conferencing platform (Zoom Video Communications, version 5.0.1) using a Microsoft PowerPoint (Microsoft Office, version 16.43) presentation. Two small group tutorials were conducted to encourage increased engagement within groups and consisted of 10 students each. The tutorial lasted approximately 30 minutes in total; 15 minutes allocated to explaining the study and requirements for participation, and then a 15-minute tutorial on the study topic. The learning objectives of the traditional tutorial were the same as the VRLE as follows:

- Facilitate a learning experience
- 3D understanding of structures
- Knowledge gain on the various stages of fetal development in pregnancy
    - Fetal development in 1st trimester i.e limb bud development; fetal heartbeat, placenta implantation
    - Fetal development in 2nd trimester
    - Fetal development in 3rd trimester
    - Fetal developmental abnormalities
    - Placental growth and function
    - Technical aspects of fetal growth i.e how to measure growth of the fetus

3.3.9 Knowledge Assessment

Student knowledge was evaluated using a multiple-choice questionnaire (MCQ), consisting of 10 questions related to the study topic. This knowledge assessment tool

was chosen as it is a commonly used assessment tool, it is time-efficient, easy to use and familiar to the participant population (Holland and Stevens, 2021). Guided by Kirkpatrick's model, knowledge acquisition was assessed using MCQ assessment as it demands simple factual recall. The learning objectives were aligned to the MCQ assessment. The MCQ was developed, and peer reviewed by experts in the field of anatomy and embryology (UCD School of Medicine) and expert clinicians in Obstetrics and Gynaecology (National Maternity hospital). MCQs were taken prior to intervention (baseline) and at two time points post intervention: immediately and after one week. The MCQ at one week was intended to evaluate knowledge retention. The time-period of one-week was chosen due to the uncertainty of COVID-19 at the time the study trial took place. The learning objectives were mapped to the MCQ assessment detailed in Table 7 below.

Table 7 Learning objectives and MCQ assessment RCT

Fetal development 1st trimester	1. In which week do we expect to see the fetal heartbeat 2. When do upper and lower limb buds develop? 3. How do we measure the length of the fetus in the first trimester? 4. At what gestation does the neural tube close? 5. When does the placenta start functioning?
Fetal development 2nd Trimester	At what stage can you determine the sex of the foetus?
Fetal development 3rd Trimester	At what gestation are the lungs considered developed?
Developmental abnormalities	1. Failure of the neural tube to close could result in what abnormality? 2. What is the most common type of spina bifida? 3. If midgut herniation fails to close, what abnormality does it result in?
Placenta	When does the placenta start functioning?
Technical questions	How do we measure the length of the fetus in the first trimester?

3.3.10 Learning Experience Evaluation

In addition to the study MCQ, participants were also asked to complete two scales on the learning experience and a VR design questionnaire (intervention group only) immediately post intervention. The two scales were designed to evaluate teaching methods and included the Student Satisfaction and Self-Confidence in Learning Scale (SCLS) and a Simulation Design Scale (SDS; renamed and adapted for the purpose of this study as Virtual Reality Design Scale (VRDS)) (Table 8) (Rizzolo et al., 2015). The SCLS explores the attitudes and opinions of the learners in relation to their learning experience. The SDS relates to the characteristics of the design of the simulation.

Both scales are validated and were originally designed for evaluation of simulation studies. In 2005, Jeffries published a framework for simulation, including the design, implementation and evaluation components. This led to a standardised theoretical framework for simulation-based healthcare education. The key elements of simulation-based education include educational practices, teacher, students, simulation design characteristics and outcomes. Various learning theories guide and inform the use of simulation including principles from constructivist and experiential theories, along with adult learning and deliberate practice, which have been discussed in Chapter 1 (Kay and Kibble, 2016, Jeffries, 2005). The SDS assesses the following elements:

- Alignment with learning objectives
- Support from the educator
- Fidelity of the simulation
- Ability to provide feedback
- Debriefing

The scale provides an opportunity for learners to provide feedback to the educator on the simulation experience. This allows for future adaptation and identification of any learning issues that need to be changed or addressed in a more learner-centred approach (Unver et al., 2017).

The scales have been used most commonly within nursing education to assess various forms of simulation-based education. There have also been a few studies that have applied the evaluation tools to VR simulation. A recent protocol was published that will teach nursing students clinical reasoning skills with a VR simulation program and evaluate the learning experience using the NLN Student Satisfaction and Self-Confidence in Learning Scale (Holland and Stevens, 2021). Chaballout (2016) used the scales to assess the feasibility of Google glass for virtual simulation training in health science students (Chaballout et al., 2016).

I proposed their use in assessing the learning experience with our VRLE. I modified the language used in the evaluation scale to include terminology that relates to virtual reality and I included questions at the end of this scale on the side effects of the VR tool, as this is an important factor in consideration of user acceptance (Servotte et al., 2020b). This resulted in an adapted version of the assessment tool for our study renamed virtual reality design scale (VRDS).

Table 8 Instruments to assess attitudes and opinions on learning experience

Instrument	Subscales
Student Satisfaction and Self-Confidence in Learning	Satisfaction in Learning
	Self-Confidence in Learning
Simulation Design Scale (VR version)	Objectives and information
	Support
	Problem Solving
	Feedback/guided reflection
	Fidelity (realism)

The 13-item SCLS measured student satisfaction with the teaching activity (five items) and self-confidence in learning (eight items). The SCSL was developed and validated by the National League for Nursing in order to implement a standardised approach to assessing learning objectives and is reported to have a Cronbach alpha of 0.94 and 0.87 for satisfaction and self-confidence, respectively (Franklin et al., 2014). SCSL is used for simulation-based studies, which was adapted for assessment of the VRLE. Total scores for the scale were obtained by adding responses to all items, with a maximum total score of 65. Higher scores denote higher levels of satisfaction and self-confidence (Unver et al., 2018).

The 20-item SDS, also developed by the National League of Nursing, was used to measure elements from the framework for simulations (Jeffries, 2005). The scale is presented in 5 sections: Objectives & Information (5 items); Student support (4 items); Problem solving (5 items); Feedback (4 items) and Fidelity (2 items). Each item is scored 1-5 on a Likert scale (strongly disagree to strongly agree). Objectives and information relates to how well the student felt the learning objectives matched the information presented in the learning tool i.e VLRE. Student support refers to the perception of support during the learning experience. The section on problem solving facilitates feedback from the participant on the ability to explore and learn from a scenario. The feedback section refers to whether there was an opportunity to give feedback to the teacher on the learning tool. Lastly, fidelity refers to the realism of the learning tool i.e. if the simulation felt like reality. The reported Cronbach's alpha for the SDS is 0.92 (Franklin, 2015) (Unver et al., 2018). We assessed the reliability of both scales in the context of our study using reliability analysis for validation. Cronbach alpha scores were 0.87 and 0.89, for the SCSL and SDS, respectively (Table 9).

Table 9 Cronbach's Alpha for Satisfaction and Self-Confidence in Learning Scale and the Simulation Design Scale and the adapted version for this study

Scales	Original version, Cronbach alpha	Correlation inter-item total	VR Version study sample Cronbach alpha	Correlation inter-item total (Mean)	Correlation inter-item total (Range)
Student Satisfaction in learning and self-confidence scale	0.87-0.94	0.34-0.75	0.87	0.35	0.19-0.75
Simulation Design scale	0.92	0.35-0.69	0.89	0.36	0.34-0.75

The primary outcome was knowledge (measured by MCQ score) post intervention. Pre-specified secondary outcomes included attitudes on the learning experience assessed using the SCSL and the VDS, demonstrated in figure 24. Side effect profiles of the VRLE were also evaluated to determine the usability of VRLE as an educational tool.

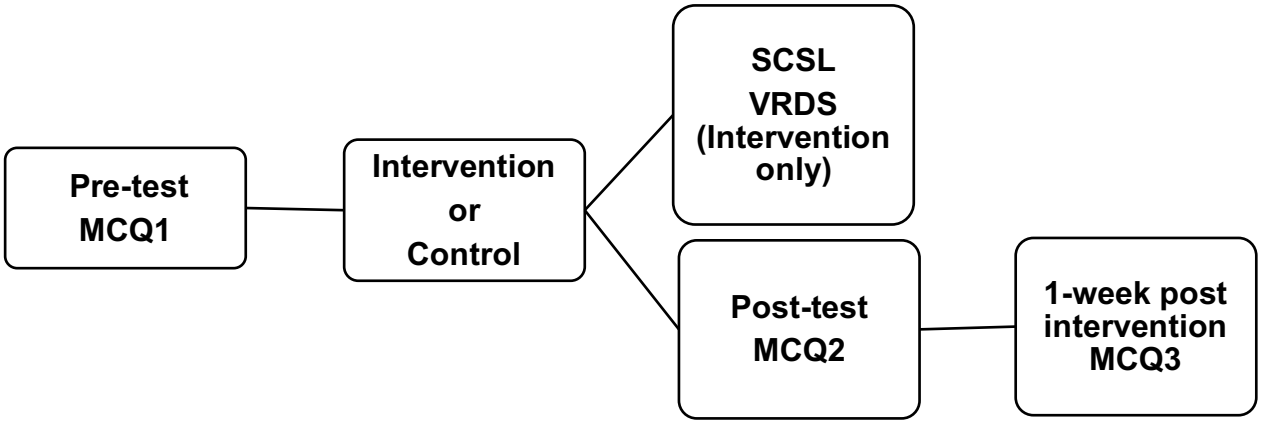


Figure 24 Flowchart of evaluation timeline

3.3.11 Qualitative Analysis

To evaluate the learning experience, we also incorporated a qualitative component to this project to gain an insight into students' experiences using both learning tools, as the VRLE is very novel and new. In the SCSL scale, participants were asked, "*Do you have any other comments to add to your learning experience today?*" and then requested to provide open-ended explanations of their opinion. In the VRDS, open ended explanations were also sought in relation to the question: "*How would you feel about incorporating the use of VR headsets as a learning tool in the classroom?*".

Students' responses were analysed using thematic analysis. Thematic analysis is defined and described by Braun and Clarke as a foundational method for qualitative analysis. It is a method for identifying, analysing and reporting patterns within data. This method was chosen as it is a "flexible and useful research tool" which can

“potentially provide a rich and detailed, yet complex, account of data” (Braun and Clarke, 2006).

Responses were transcribed verbatim from the survey by the researchers (GR and MH) and coded. Transcripts were read and reread as codes were assigned, narrowing, and redefining the codes that presented in the data initially. The codes were then observed and grouped several times until the researchers were satisfied that the themes were identified appropriately. Themes were developed from the data that were prevalent, important, and substantial across the survey. Saturation of themes was defined when refinement did not add any new substantial themes.

3.3.12 Statistical analysis

MCQ scores were compared between groups immediately post intervention (MCQ 2) and after one week (MCQ 3) using one-way analysis of covariance (Thurzo et al.). Both models were adjusted for baseline score (MCQ 1), and MCQ 2 in the latter test.

3.3.12.1 Data collection

I used the online platform Qualtrics (Qualtrics^{XM} LLC 2021) to collect the data using a UCD password protected account. The MCQ assessment, the SCSL, and the VRDS questionnaires were all uploaded to the site, which allowed distribution via QR codes and weblinks and a centralised platform for data collection. I created a second QR code link for the evaluation. The participant accessed the code using their own personal phone, by scanning a barcode that was printed on a sheet during participation in the study. This also reduced the risk of transmission of COVID-19 and was in line with public health guidance at the time. Email links to MCQ3 were sent one-week later. Once data collection was complete, I downloaded the data to both an

Excel master document and SPSS 24.00 software (IBM Corporation, Armonk, NY USA). Access to the data and the computer were password protected.

Data was tested for normality prior to assessment using Shapiro-Wilk tests. Homogeneity of variances was evaluated using Levene's test, and in instances where this assumption was violated, the Welch correction was used. Statistical analysis was performed with SPSS 24.00 software (IBM Corporation, Armonk, NY USA) and an alpha value of 0.05 was considered statistically significant. Mean (standard deviation; SD) results are reported in text, unless data was non-parametric.

3.4 Results

3.4.1 Quantitative analysis

Fifty-six medical students volunteered to participate in this study. Of the fifty-six medical students, forty-one (73%) completed the study, with twenty-one and twenty participants in the intervention and control groups, respectively. Baseline characteristics of study participants are outlined in Table 10 and reported in accordance with the CONSORT guidelines (Schulz et al., 2010). The majority of participants (61%) were aged 25-34 years, with the remaining 39% being 18-24 years of age. Thirty (73%) of participants were female and 11 (26%) were male; 14 (34%) were from the undergraduate medical degree programme, while 27 (66%) were on the graduate degree programme.

Table 10 Baseline characteristics for intervention and control study groups. Group size (n) and percentage (%) of overall group size are reported

	Overall (n = 41)	Intervention (n = 21)	Control (n = 20)	
Age (Kaka et al.)				P=1.00
18-24	16 (39%)	8 (38%)	8 (40%)	
25-34	25 (61%)	13 (62%)	12 (60%)	
Gender				P=0.18
Male	11 (27%)	8 (38%)	3 (15%)	
Female	30 (73%)	13 (62%)	17(85%)	
Course				
Undergraduate Medicine	14 (34%)	8 (38%)	6 (30%)	P=0.55
Year 1	0	0	0	
Year 2	0	0	0	
Year 3	1(7%)	1 (5%)	0	
Year 4	7 (50%)	4 (19%)	3 (15%)	
Year 5	5 (36)	3 (14%)	2 (10%)	
Year 6	1 (7%)	0	1 (5%)	
Graduate Medicine	27 (66%)	13 (62%)	14 (70%)	P=0.12
Year 1	0	0	0	
Year 2	10 (37%)	3 (14%)	7 (35%)	
Year 3	11 (40%)	5 (24%)	6 (30%)	
Year 4	6 (22%)	5 (24%)	1 (5%)	
VR experience	16 (39%)	4 (19%)	12 (60%)	P=0.02

With regard to the primary outcome testing the effect of intervention on MCQ knowledge scores, there were no statistically significant differences in the MCQ 2 (*P* = 0.91) and MCQ 3 (*P* = 0.97) outcomes between the intervention and control groups (Table 11).

Table 11 Multiple choice questionnaire (MCQ) test scores for intervention and control groups at time points 1-3

Time Point	Intervention (n = 21)	Control (n = 20)	Mean Difference	Corrected P value	95% CI
MCQ 1	4.43 (1.86)	5.45 (1.67)	1.02	0.58	-
MCQ 2*	6.67 (1.11)	6.75 (1.21)	0.08	0.91	6.34, 7.07
MCQ 3#	6.19 (1.17)	6.15 (1.18)	-0.04	0.97	5.86, 6.48

*ANCOVA corrected for baseline (MCQ 1) scores.

#ANCOVA corrected for baseline (MCQ 1) and post-intervention (MCQ 2) scores.

Mean scores and standard deviation presented.

Pre-intervention there is no statistically significant difference in knowledge scores between the groups (*P*= 0.58). Knowledge scores improve in both groups immediately post-intervention, but this is not statistically significant. Mean scores are higher in the control group (6.75 (1.21) compared to the intervention group (6.67 (1.11)). Knowledge scores 1-week post intervention also showed no statistically significant difference. There was no statistically significant difference in the secondary outcomes of SCSL scores between groups (Table 12).

Table 12 Student Satisfaction and Self Confidence in Learning Scale (SCSL) scores for intervention and control groups

Scale	Intervention (n = 21) (Mean (SD))	Control (n = 20) (Mean (SD))	Corrected P-value	95% CI
Total SCLS Score*	54.19 (7.54)	50.45 (7.20)	0.21	47.14, 54.24
Satisfaction in Learning	21.57 (3.67)	19.55 (3.27)	-	-
Self-Confidence in Learning	32.62 (4.42)	30.90 (4.64)	-	-

*ANCOVA corrected for previous virtual reality use.

Total and subgroup scores reported are means (SD). The Students' Satisfaction and Self-Confidence in Learning Scale is a 13-item instrument Likert-style scale with scores ranging from 1 = strongly disagree to 5 = strongly agree. It is divided into two subscales, satisfaction in learning and self-confidence in learning.

VRDS mean item scores per section are reported for each design feature in Table 13. Objectives and information (4.70) and support (4.80) were rated the highest among the design features. In reference to fidelity and resemblance to real life, students also reported high levels of realism (3.90).

Table 13 Virtual Reality Design Scale Scores (VRDS) in intervention group only

Questionnaire Item	Mean Item Score*
Objectives & Information	4.70
Support	4.80
Problem Solving	4.35
Feedback	4.35
Fidelity (Realism)	3.90

*Mean item score per section reported for intervention group only.

VRDS is an18-item instrument to rate the design of the VRLE with scores ranging from 1 = strongly disagree to 5 = strongly agree.

Table 14 describes the side effects experienced by participants in the intervention group. The most commonly reported side effects were disorientation (48%), dizziness (43%), impaired balance (38%), and symptoms similar to motion sickness (38%).

Table 14 Virtual Reality Learning Environment side effects experienced by participants

Side Effect	Number affected (%)*
Eye or muscle twitching	0 (0%)
Excessive sweating	0 (0%)
Increased salivation	0 (0%)
Discomfort or pain in the head or eyes	0 (0%)
Drowsiness	0 (0%)
Fatigue	0 (0%)
Involuntary moving	1 (5%)
Impaired hand-eye coordination	1 (5%)
Headache	2 (10%)
Loss of awareness	2 (10%)
Light-headedness	2 (10%)
Eye strain	3 (14%)
Blurred/Altered or Double vision	5 (24%)
Nausea	5 (24%)
Impaired balance	8 (38%)
Any symptoms similar to motion sickness	8 (38%)
Dizziness	9 (43%)
Disorientation	10 (48%)

*Percentage values calculated from overall intervention group size (n=21). Participants completed a questionnaire on the side effects experienced during the VRLE.

Over one third (38%) of participants reported no symptoms during the intervention, whereas 19% experienced one or two symptoms, 24% experienced three to four symptoms, and 19% experienced five or more symptoms.

3.4.2 Qualitative Analysis

Three themes were developed from thematic analysis of the free text answers; “Learning in 3D”, “The use of educational technology” and “Learning can be fun and enjoyable”. Students within the control group were mostly appreciative of the lecture format, reporting that the *“pace of the lecture was good”* [P1], stating the lecture was *“… very informative”* [P12] and a *“good learning experience overall of a topic that I personally don’t find very accessible”* [P3].

Learning in 3D

Participants postulated their perceived opinions of VR, suggesting that it may be *“…very useful for understand the 3D twists and turns involved in embryology”* [P2] and that it may help specific visual concepts such as *“sequence of gut development, where it would shine”* [P7].

Having experienced VR for teaching, their experience mirrored the postulations of their colleagues where *“VR …seems to allow for greater appreciation of complex 3D structures”* [P10] that was *“very helpful for visualising embryology”* [P8] with some qualifiers *“would take some getting used to”* [P18].

The use of educational technology

In relation to the VDS, most students thought it would be a useful learning tool in the classroom, suggesting that it is *“…….a great addition”* [P21], *“a valuable asset”* [P13], and a *“novel learning tool”* [P1].

Students seemed to understand the potential added value that learning with VR could have in the classroom: *“I think it would be a good move, it seems useful in the*

explanation of complex structures that can often be difficult to visualize" [P10] and *"I think this would be very useful as it is an extremely immersive experience and thus more stimulating and enjoyable to learn in"* [P19].

Some students acknowledged the potential benefits of VR even though they experienced side effects during the VRLE, *"It makes me a bit dizzy but other than that it is very fun and interesting and would help me to learn better than usual lectures, or at least would enhance my learning along with lectures"* [P20] and *"I think it's a good idea"* [P16]. Other comments included the following: *"It personally made me feel quite dizzy/ disorientated but I think if we got used to them, they would be a great learning tool"* [P16] and *"While it certainly has its benefit, I did experience some motion sickness and as such would be concerned about the need to use it for all the teaching"* [P14].

Learning can be fun and enjoyable

There was some yearning for the VR experience, with participants wistfully suggesting that it would be *"a fun and engaging way of learning"* [P5].

Within the VR group, students praised the novelty and innovation of VR, as a "fun new way to interact with information*"* and "*A nice change from the traditional lecture format!"* [P17], where they reported that VR was *"very cool"* [P6] and that *"I LOVED IT"* [P7].

3.5 Discussion

I successfully developed a bespoke design VRLE (called “VR Baby”) on topics pertaining to the Obstetrics and Gynaecology curriculum in collaboration with the UCD Computer Science team. The VR learning tool was developed using the VRID model. A conceptual framework supported by principles of constructivism and experiential learning theory guided the lesson plan and learning objectives. A randomised controlled trial was conducted to compare student knowledge of fetal development during pregnancy with a VRLE vs a traditional PowerPoint tutorial. Primary outcomes evaluated knowledge acquisition; secondary outcomes evaluated the learning experience using validated instruments. A qualitative analysis provided an insight into participants’ opinions of “VR Baby”. Results of our primary outcome demonstrate equal levels of knowledge acquisition post-intervention with no statistically significant difference between groups. Results of the SCSL questionnaire reflect a high degree of satisfaction in learning and self-confidence with the VR learning tool. Qualitative analysis favoured the use of “VR Baby” despite a high incidence of side effects.

As best practice guidelines suggest, the VR learning tool was designed using an instructional design model (Issenberg et al., 2005). The VRID model, as proposed by Chen, guided the development of our VRLE in a standardised format. The lesson plan was guided by a conceptual framework informed by principles from constructivism, experiential learning theory and multimedia learning theory. Based on experiential learning theory, the VRLE created a learning experience for the learner by immersing them in a 3D world to learn about the developing fetus during pregnancy. Users could explore information visually presented, manipulate objects and abstract information in a game-like learning environment. Users ‘clicked’ on the fetus to reveal a text box of information containing answers to the post-intervention assessment. Presenting

information in this way is thought to reduced cognitive overload based on Mayer's cognitive theory of multimedia learning (Mayer, 2005). The VR tool provided a learning opportunity to combine prior basic 2D knowledge with 3D visualisation allowing the learner to integrate learning activities and connect experiences. This supports principles from constructivism, allowing the user to construct their own knowledge in real time in a self-regulated process. Applying educational theory to the development of "VR Baby" allowed us to develop a VR learning tool. As concluded by a systematic review carried out by BEME, under the right circumstances, with clearly defined conceptual frameworks and learning objectives, high-fidelity simulation, including immersive technologies, is an effective way for trainees to learn (Issenberg et al., 2005).

Our study findings are supported in the literature. Research to date suggests that VR technology results in equal or higher levels of knowledge of complex anatomical relationships with VR learning tools (Zeiger et al., 2017, Aksoy, 2019, Maresky et al., 2019a). The primary outcome of this RCT was knowledge gain. The primary outcome measure was closely aligned with the learning objectives and the MCQ assessment. Our study findings showed no difference in post-intervention knowledge scores between groups. This could be due to a variety of factors. The pre-test results reveal a high baseline knowledge and familiarity of the pre-intervention test may have influenced learning during the intervention. Furthermore, the heterogeneity of student learning stages could also have been an influencing factor. Due to COVID-19, accessing a naïve group of participants at the same learning stage was not possible. Due to timing constraints, there was a 1-week interval between pre-and post-intervention assessment. Perhaps a longer interval between pre-and post-intervention assessments could have reduced the familiarity of the MCQ assessment. A future

study should include a population with a naïve group of participants at the same learning stage to mitigate the above-mentioned factors.

Secondary outcomes evaluated participant self-confidence and satisfaction with the learning tool in addition to evaluating the design of the “VR Baby”. Qualitative analysis revealed a positive attitude and high levels of satisfaction and self-confidence with the VRLE. These finding suggest that students enjoy learning with this technology and feel more confident in their understanding of the lesson content. Although VR has been around for some time, it may still be a novel learning tool for some, and participants are generally curious and excited to explore it (Wainman et al., 2019). Studies that have compared VR learning tools with traditional 2D learning tools also report similar findings that VR is considered to be an enjoyable and fun way to learn (Stepan et al., 2017a, Chen et al., 2020).

The VRDS evaluated user views and design features of “VR Baby”. With regard to objectives and information, results reflect participants’ agreement that the learning material and information presented matched the learning objectives of the lesson. Participants also rated the fidelity of the learning tool highly suggesting a close resemblance to real life. Users also perceived the VRLE as easy to use and comfortable to wear. Evaluation of student perspectives on learning is an important component of medical education (Paterson et al., 2020). It helps educators to understand how students prefer to learn and improve lesson quality. With the continuous advancement of technology and availability of more modern technology, VR learning tools are being built to higher specifications which result in more meaningful learning experiences. VR can be considered as a valuable supplementary

educational tool, which is a very exciting prospect for both students and curricula developers alike (Moro et al., 2017a).

The thematic analysis reflected an overall positive response to the VRLE. Users postulate on the usefulness of VR to explain complex structures that can often be difficult to visualise. Participants' comment on the immersive ability of VR to enhance the learning process and make it more engaging. These findings support VR user acceptance amongst participants in this study and are reflected in the literature (Yammine and Violato, 2015). Living in an era of digital natives there is an expectation from students to find technology within the classroom. However, it is important to note that immersive technologies may not replace traditional lecture-based teaching by experts but may serve as a valuable educational tool, enhancing and reinforcing knowledge, clinical reasoning, and skills.

Although participants favour VR technology, adverse effects of VR may be a limiting factor in its acceptability as a learning tool. A major limitation of these devices is cybersickness. The VRDS scores demonstrated a high incidence of side-effects associated with the use of our VRLE. In addition the feedback from our thematic analysis also raises concerns about the side-effect profile. In this study, almost half of the participants using VRLE experienced disorientation. However, despite the side effects experienced by the participants, they still gained knowledge and scored highly on the satisfaction with learning scale. In the future, with increased use of VRLEs and the advancement of the technology used, the side effect profile is expected to decrease (Servotte et al., 2020a).

3.5.1 Strengths and Limitations

To the best of my knowledge this study represents the first step towards exploring the role of VRLEs as a valuable learning tool in medical education in our education centre at UCD. A vast number of VR learning tools have been developed in the literature however my literature review found that very few studies detail the development and theoretical process. The development of "VR Baby" using this model to facilitate learning is a strength of this study. The use of a model such as VRID can provide a standardised development guide for educators developing VR learning tools.

A strength of our study is that we implemented and adapted tools to evaluate the learning objectives of "VR Baby". Chapter 2 of this thesis reports that there are no standardised tools to evaluate the learning objectives related to the learning experience of VRLEs, including satisfaction, self-confidence, motivation and engagement. I noted the lack of standardised validated tools to evaluate the use of immersive technology in healthcare student education. This study attempted to assess the educational effectiveness of a VRLE by assessing a combination of knowledge, attitudes and perceptions of the learning experience. Based on this, I utilised instruments (SLCS and SDS) that were validated for use in simulation studies and adapted them for use within our study (SLCS and VRDS), in an effort to propose a standardised approach to evaluate the learning experience of an immersive learning tool. Reliability assessment of the scale for our study further validated its use within our study with acceptable levels of Cronbach alpha reported (0.87 and 0.89 for SLCS and VRDS respectively). However this author notes that the reported values for inter-item correlation (range) of both the original SCSL (0.34-0.75) and SDS (0.35-0.69), and adapted versions of the SCSL (0.19-0.75) and VRDS (0.34-0.75) were both higher than the accepted average range (0.15-0.5). This finding suggests that some items in

the adapted SCSL scale items are not well correlated. This may indicate that some of the items on the scale do not correlate well with the questions being asked. Future studies should include a revised scale that includes more suitable questions or perhaps remove those items from the scale. Nonetheless, a standardised tool would provide a consistency of reporting participant learning experiences with VR learning tools. This will contribute to the growing body of evidence on VR learning tools and may strengthen the evidence for its usability within medical education.

Evaluation of the side-effect profile associated with “VR Baby” is another strength and important finding in this study. Our study found a high incidence of side effects following the intervention. Approximately 50% of participants experienced disorientation. There is a paucity of information or reporting of side effects associated with VR learning tools in medical education (Kyaw et al., 2019c). Therefore, this finding is an important contribution to the research on VR learning tools. This study finding can inform future research and contribute to the growing body of evidence on the use of VR technology.

A systematic review by the Digital Health Education Collaboration suggests that VR results in equal or increased levels of knowledge acquisition in 8 out of 31 studies, however the certainty of evidence according to the GRADE criteria ranged from low to moderate (Kyaw et al., 2019d). This is consistent with the study findings of our systematic review in Chapter 2 that found when compared to traditional educational tools immersive educational tools i.e. VR, AR, or MR demonstrate equal or improved knowledge acquisition and an enhanced learning experience. Therefore knowledge gain was an outcome of interest of this study that we wanted to explore. However findings in the literature to date also demonstrate that a key strength of VR learning

tools is their ability to enhance 3D understanding and spatial awareness of complex anatomy and embryology. A limitation of our study design is that the primary outcome did not evaluate the enhanced 3D understanding of complex structures pertaining to embryology topics. On reflection this author acknowledges that this integrative goal of VR was not aligned with the learning objectives and the assessment of the intervention. In the future I would give more time to considering the integrative goals and how best to assess understanding of 3D structures using VR in this step of my research. A primary outcome that combined assessment of factual knowledge and understanding of spatial relationships would have been better suited to evaluate the strengths of the VRLE. This would involve developing and adding questions to the MCQ that assess understanding and spatial awareness of 3D structures. In the literature the vast majority of studies on VR learning tools measure knowledge as the primary outcome. A meta-analysis of 36 studies, including 28 RCTs and 2226 participants showed that 3D visualization technology was associated with higher factual knowledge, better results in spatial knowledge acquisition, increased user satisfaction, as well as growth of learners' perception of tool effectiveness (Yammine and Violato, 2015). Out of 36 studies, 21 studies assess knowledge acquisition as the primary outcome in a pre-test/post-test design. Three studies identified in the analysis tested spatial awareness with 3D questions to evaluate 3D understanding (Fritz et al., 2011, Hisley et al., 2008, Naaz, 2012). This author acknowledges that an imbalance between the two groups in baseline variables may have influenced the outcome, leading to the possibility of chance bias in the analysis of our results.

Other limitations include the fact that the findings from this study are based on a single intervention and setting. Future research with a greater sample size and use of similar interventions will be required to validate the findings and further establish the use of

immersive technologies in medical education. Lastly, the VRLE lesson was very short and evaluated in a short period of time due to the COVID-19 pandemic. With regard to the secondary outcomes of the RCT, the study was not powered for the secondary outcomes. Future studies should include larger sample sizes and be powered for the secondary outcomes, in addition to evaluating the strengths of the VRLE.

3.6 Conclusion

This study explored the use of VRLEs compared to a traditional tutorial, as educational tools to gain knowledge of complex anatomical structures, such as those found in the obstetrics and gynaecology curriculum. Results demonstrated there are no statistically significant differences in knowledge with a VRLE compared to traditional tutorial. Qualitative analysis findings favoured the use of VR by medical students however the side effect profile may be a limiting factor. This study adds to the existing research on the use of VRLEs in medical education, specifically in relation to knowledge acquisition, the learning experience and side-effect profile.

Chapter 4 “VR Baby”, A Virtual Reality Learning Environment for Midwifery Students: A Mixed Methods Study

Manuscript accepted for publication with Nurse Education Today: G Ryan, S Callaghan, AR Rafferty, J Murphy, M Higgins, T Barry, E Mangina, L Carroll, F McAuliffe. Virtual Reality in Midwifery Education: A Mixed Methods Study to Assess Learning and Understanding

4.1 Summary

4.1.1 Background

There is a paucity of evidence in the literature supporting the use of virtual reality learning environments (VRLEs) within Midwifery education.

4.1.2 Objectives

The aim of this study is to explore the effectiveness of a VRLE as an educational tool in midwifery education.

4.1.3 Methods

Participants underwent a VRLE lesson based on the topic of fetal lie, position, and presentation in pregnancy. A multiple-choice questionnaire was used to quantitatively evaluate knowledge before and immediately after the intervention, and knowledge retention after one week. Qualitative data was collected using open-ended questions in the questionnaire. The primary outcome was a difference in pre- and post-intervention knowledge scores. Data was analysed using repeated measures one-way ANOVA. Qualitative data was analysed using thematic analysis and simple content analysis. All students participated in the quantitative and qualitative components of the study. Secondary outcomes included participant satisfaction and self-confidence in learning which were analysed using thematic analysis. The side effect profile of the virtual reality device was also explored using open-ended questions in the questionnaire.

4.1.4 Results

Forty-one midwifery students participated in the study, with a 100% participation and response rate. Repeated measures one-way ANOVA revealed no statistically significant differences in knowledge scores pre- and post-intervention. Participants rated high satisfaction and self-confidence scores with regard to the VRLE as a learning modality. Side effects most commonly experienced by participants included dizziness (49%), disorientation (30%) and symptoms similar to motion sickness (32%). The following themes were identified: “Learning in 3D”, “The Power of Visual Learning”, “The value of Educational Technology”, “Learning can be fun and enjoyable”.

4.1.5 Conclusions

This study showed that the VRLE had no impact on knowledge gain, though high levels of satisfaction and self-confidence indicate a positive response to the VRLE. VRLEs are a potentially valuable learning tool to help enhance the student learning experience, promoting increased engagement, satisfaction, and self-confidence with the learning material.

4.2 Introduction

VRLEs could revolutionise teaching and learning for midwifery and nursing students by providing a learning experience that can enhance understanding of complex anatomical structures and help to develop important skills such as: team-work, collaboration, critical thinking and problem solving skills (Fealy et al., 2016).

As discussed in Chapter 1, the underlying value of VR technology for healthcare education is the ability for VR to create an environment for practicing basic clinical skills and to visualise 3D objects for enhanced understanding of complex topics. Spatial ability is a vital component in students' cognition for learning and is described as "*the ability to generate, retain, retrieve, and transform well-structured visual images*" (Sun et al., 2019). Examples of complex concepts related to pregnancy and midwifery include fetal anatomy and circulation, and the orientation of the fetus within the uterus and pelvis. These concepts present unique difficulties for medical and midwifery students' learning. This is due to the inability to access cadaver models of the fetus and pelvic anatomy in pregnancy to visualise structures, as utilised to teach other areas of human anatomy. VRLEs immerse the student in a 3D world, which may increase their understanding of the fetus inside the uterus. A recent study published by Fairén (2020) trialled the use of VR to teach anatomy. A VRLE was developed for anatomy teaching on various human organs and participants evaluated the tool by completing a questionnaire (Fairén et al., 2020). The study concluded that a VRLE is a self-directed learning tool that can facilitate understanding of the volume and relationship among the different anatomical structures. This finding also supports the strengths of VRLEs and how principles of constructivism and experiential learning apply to VR learning tools. As discussed in Chapter 3, the development of effective

educational VR tools should be guided by a conceptual framework and an instructional design model that are supported by educational theory (Issenberg et al., 2005).

There is a paucity of literature on the topic of VR within nursing and midwifery education. A meta-analysis on the effectiveness of VR within nursing education provided a comprehensive overview on the role of VR in a total of twelve studies (Choi et al., 2022). Outcome measures included: knowledge, skills, satisfaction, confidence and performance time. The study concluded that VR could improve nursing students' knowledge, however there was no difference in the other outcome measures. The systematic review presented in Chapter 2 also finds a lack of research on VR within this population. Out of 29 RCTs, eight studies include nursing students, and no studies involve midwifery students. Further research is required to explore the educational effectiveness of VR within nursing and midwifery education. With this in mind, I conclude that midwifery and nursing education has a unique need for VRLEs as an educational tool to enhance learning and understanding of the fetus during pregnancy and associated pelvic anatomy.

I have already conducted a randomised controlled trial in a population of medical students that concluded a VRLE led to similar knowledge gain comparable to a traditional tutorial. The aim of this study was to explore the role of VRLEs in a population of midwifery students. I developed a 3D lesson for "VR Baby", a VRLE on the topic of "*fetal lie, position and presentation in the womb during the pregnancy*". Again, it was developed using the same conceptual framework in chapter 3, based on the learning theories of experiential learning and principles of constructivism coupled with Mayer's cognitive theory of multimedia learning. The primary aim of this study is to investigate whether a VRLE increased knowledge or knowledge retention in

midwives. Secondary outcomes of interest include the impact of the VRLE on the learner experience and associated side effects of the technology.

4.3 Methods

4.3.1 Study design and setting

This mixed methods study assessed the educational effectiveness of a VRLE in midwifery education. The study was conducted between September 2020 and March 2021. Ethical approval was granted by the University Research Ethics Committee on the 7th of July 2020, as an amendment to the ethics received for the RCT in Chapter 3 (Reference: LS-20-09-McAuliffe). The study was registered with the ISRCTN trial registry (ISRCTN ID:12735607). The ethics approval letter and study trial protocol can be found in the appendices. Although the study design of the 3D lesson developed for "VR Baby" followed the same process as the RCT presented in Chapter 3, I developed a VRLE on a topic of relevance for midwifery students, "*fetal lie, position and presentation in the womb during the pregnancy*". The evaluation consisted of a pre- and post-test of a single cohort of participants.

4.3.2 Participant recruitment

Midwifery students were invited to participate in the study through the university e-platform "Brightspace" and class announcements. Further recruitment took place during the midwifery students' clinical practice placements in the university's affiliated maternity hospital, The National Maternity Hospital by way of in person class announcements of the study. At University College Dublin there are two Midwifery programmes. Firstly, Bachelor of Science which is a four-year undergraduate programme. The second programme is the Higher Diploma (postgraduate) in Midwifery, which is an 18-month course for registered general nurses who want to

become midwives. Midwifery students from the BSc programme and Higher Diploma programme, who had completed university-based lectures on the topic of fetal lie, position, and presentation in pregnancy, were eligible to take part in the study. Exclusion criteria included students that had not completed the standard lectures on the topic, non-English speaking, under the age of 18, or existence of a medical condition including cardiac (e.g., pacemakers) and binocular vision abnormalities, psychiatric disorders, or epilepsy. Students expressed interest to participate in the study via a clinical midwifery placement coordinator. All students that expressed interest were eligible to take part.

Participants were informed that their participation was voluntary and would not impact the outcome of their clinical assessment. Written informed consent was obtained and the COVID-19 protocol (i.e., public health guidance on hand and respiratory hygiene and social distancing) was followed throughout all stages of the study. The COVID-19 protocol was guided by advice from Public Health authorities, this meant that participants were required to wear a face mask during study participation, perform hand-hygiene prior to participating, and keep a distance of two-metres, unless help was required by the researcher. Students were informed that they could withdraw from the study at any point, without any impact on their clinical standing. For data analysis purposes, I recorded student university identification numbers and each student was then assigned a study identification number in order to pseudo-anonymise participation and results. The researcher conducting the investigations was not blinded to participant or study group allocation, given the nature of the study design.

4.3.3 VRLE Development

The VRLE was developed in a similar way to the VRLE on the topic of "*Stages of Fetal Development*" (Chapter 3, Section 3.3.4). The VRLE created for the Midwifery students was a review lesson on the topic of "*Fetal lie, position, and presentation in the third trimester of pregnancy*". An example is illustrated in Figure 25.

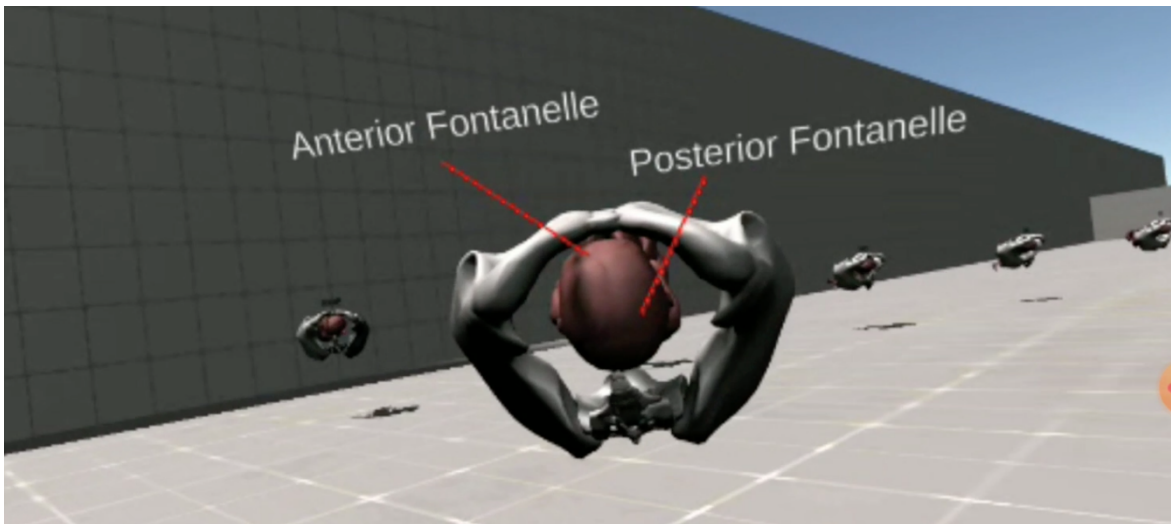


Figure 25 Example of view through the VR headset of the fetal head presentation, with the fontanelle highlighted

To summarise the development process of the VRLE, which was also developed in collaboration with the University's School of Computer Science. An instructional design team-based approach was implemented and the learning theory behind the lesson was guided by the conceptual framework on experiential and constructivism learning theories. The lesson then used Kerns 6-step approach to curriculum development to guide the learning plan and learning objectives. The learning objectives of the VR learning tool are as follows:

- Facilitate a learning experience

- Knowledge gain on the topic of Fetal lie, position, and presentation in the third trimester of pregnancy
    - Types of fetal lie
    - Fetal positions in the 3rd trimester
    - Fetal presentation in the 3rd trimester
    - Placental abnormalities
- Enhance understanding of 2D images of fetal development in pregnancy by converting them into 3D in a VRLE
- Increase learner self-confidence and satisfaction with study material

As mentioned previously, the design of the VRLE was based on a combination of online tutorials and documentation in the literature regarding VRLE development (Allen et al., 2016a, Chang et al., 2017, Werner et al., 2017). Experts in the field were consulted on the curricular content of the embryology modules on the midwifery course so that the VRLE design could reflect the standard of education required for successful completion of the course. This included knowledge of the fetus in relation to the pelvis, the lie of the fetus in the womb, the various presentations of the fetus in the third trimester e.g., breech presentation Using basic stereolithography (3D image files) obtained from CGT-trader (an online 3D model marketplace), a 3D lesson was built in steps using opensource software including Blender (version 2.91.2), (Govea-Valladares et al., 2018) and Unity 3D (version 2020.2.1) to create a VRLE compatible with an Oculus Quest HMD and controllers. Images of the VRLE on the topic of "*Fetal Lie, Position and Presentation in the third trimester of pregnancy*" are shown in Figure 26. To ensure a medically correct reconstruction of the 3D learning objects, I sought expert validation by Obstetrics and Gynaecology Professionals in conjunction with Midwifery professionals. This also contributed to the face validity of the learning tool.



Figure 26 Example of view seen by participants of breech presentation through the VR headset

4.3.4 VRLE Tool

This study also took place during the COVID-19 pandemic as a result the learning experience was carried out under government directed protocol and guidance. Public health guidance was followed i.e. hand and respiratory hygiene, in conjunction with social distancing guidelines. Participants were scheduled two to four at a time and the study took place in a large lecture room with adequate ventilation. Of note, no participants contracted COVID-19 during the running of this study. Participants were given a short introduction on the use of the VR headset and controls and were then instructed to use the headset for a 15-minute period. Again, similar to the previous VRLE, this VRLE was interactive involving a "*treasure hunt*" for information linking images to key learning points relating to the topic. Students had to answer questions during the lesson, as seen in Figure 27. Using the controllers, participants progressed through a "*maze*" to find the learning objects and answered practice questions throughout the lesson in relation to the displayed images to correlate clinical knowledge.

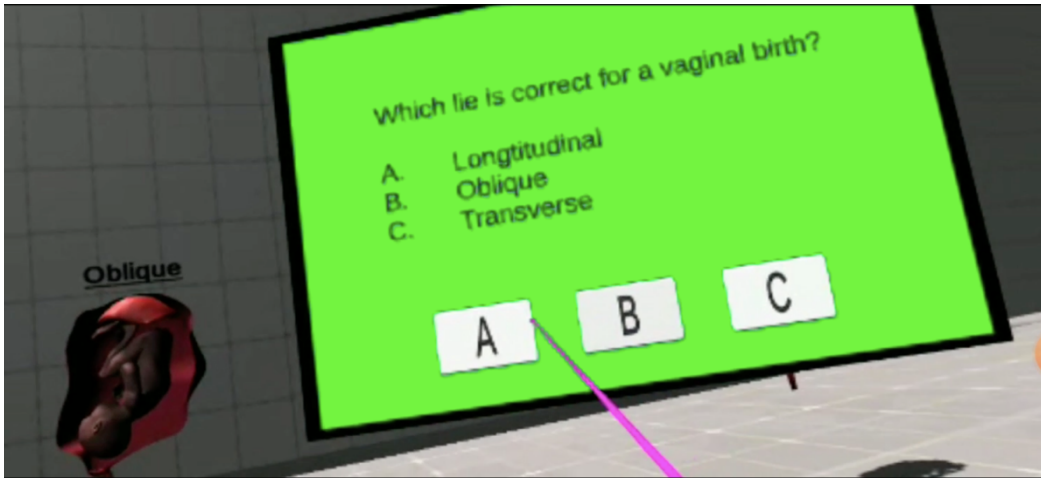


Figure 27 Interactive view of participant selecting the correct answer during the VRLE

4.3.5 Knowledge Assessment

The primary outcome of this mixed methods study was difference in knowledge scores pre- and post-intervention. The learning objectives were mapped to the MCQ assessment (Table 15). Student knowledge was evaluated using a multiple-choice questionnaire (MCQ), consisting of ten questions related to the topic of the VR lesson, "*Fetal lie, position and presentation in the third trimester of pregnancy*". This MCQ was also developed and peer reviewed by experts in the field of Midwifery and Obstetrics and Gynaecology. MCQs were taken prior to intervention (baseline) and at two time points post intervention: immediately following exposure to the VRLE and one week following the intervention. The participant took MCQ1 and MCQ2 on the study day, online by scanning a bar code on their personal smart phone which linked them to the MCQ stored on the Qualtrics platform. The MCQ at one week was sent by an email with the link to MCQ 3, which was also on Qualtrics. Following knowledge assessment, the learning experience was evaluated using the same validated scales as used in the RCT; namely: the SCLS and the VRDS. I used the adapted version of these validated scales (SCLS and VRDS) as described in Chapter 3, Section 3.3.7 (Rizzolo et al.,

2015). This was also accessed after the intervention via scanning a bar code link to the Qualtrics platform. The primary outcome was knowledge (measured by MCQ score) post intervention. Pre-specified secondary outcomes included attitudes and opinions of the learning experience assessed using the SCLS and the VRDS. Side effect profiles and content validity of the VRLE were also evaluated to determine the usability of VRLEs as an educational tool.

Table 15 Learning Objectives and MCQ Assessment Cohort Study

Types of Fetal Lie	Define unstable lie
Fetal presentation in the 3rd trimester	1. What type of breech presentation is described as both legs flexed at the hips and knees? 2. What type of presentation is most suitable for a vaginal birth? 3. When the fetal buttocks is the presenting part, this is known as? 4. What risks are associated with breech presentation? 5. What are the current guidelines on the management of the delivery of a breech presentation? 6. What does fetal presentation refer to?
Fetal position in the 3rd trimester	What is the most common position of the fetal head at birth?
Placental abnormalities	1. How can we describe the condition known as placenta praevia? 2. Which of the following is a known complication associated with placenta previa?

4.3.6 Qualitative Analysis

Data from student responses were analysed using Thematic Analysis (Braun and Clarke, 2006). Again, this method was chosen as it provides consistency in the thesis. This method provides a "*flexible and useful research tool*" which can "*potentially provide a rich and detailed, yet complex, account of data*". The SCLS also included

open-ended questions where participants were asked to provide additional comments on their learning experience (Question 4-7 on the SCLS section entitled Learning Experience Student Questionnaire (See attached supplementary file)).

The questionnaires were anonymous, using identification codes as previously described in an effort to reduce bias and to strengthen the rigour of the analysis. Anonymised responses were compiled into one Microsoft Word document for Thematic analysis (Braun and Clarke, 2006). The research question was placed at the top of a word document. Next, the responses of the anonymised questionnaires were all extracted from the questionnaires and put into one-word document.

To further enhance the rigour and trustworthiness of the analysis, the responses were read and analysed by two reviewers independently. Similar responses were first grouped together and coded in a systematic format based on the research question. The two reviewers familiarised themselves with the data, which made identifying similar themes easier. These themes were then grouped together and defined further. The two reviewers came together to further review and redefine themes as necessary. and similar responses were grouped together.

In the VRDS, open-ended explanations (Question 19 on the VRDS Questionnaire) were also sought in relation to the question regarding students' thoughts on incorporating VR headsets in classroom learning environments. Participant responses were analysed using simple content analysis. Anonymised participant responses were gathered and placed in a Microsoft Word document. The frequency of patterns in the responses were evaluated and grouped according to similarity by two reviewers.

Content analysis allows direct examination of the text, in addition to allowing for valuable insight into the thoughts of participants on the introduction of educational technology such as VRLEs.

4.3.7 Statistical analysis

The statistical analysis was also carried out in a similar approach to the RCT, however as there was no comparison group, I concentrated on analysing any differences between time points. MCQ scores were compared between each time point, from baseline to immediately after the VRLE (MCQ 2) and after one week (MCQ 3) using repeated measures one-way ANOVA.

Again, similarly to the RCT, I used the online platform Qualtrics to collect the data. This allowed me to distribute the evaluation instruments online via the use of QR codes and online links as described above and again reducing the risk of COVID-19. Data was downloaded into an excel master database and Statistical Package for Social Sciences (SPSS version 24) (IBM Corporation, Armonk, NY USA).

Data were tested for normality prior to assessment using Shapiro-Wilk tests and QQ plot assessment. Statistical analysis was performed using the SPSS and an alpha value of 0.05 was considered statistically significant. Mean (standard deviation; SD) results are reported in text unless data was non-parametric.

4.4 Results

4.4.1 Quantitative analysis

Forty-one midwifery students participated in the study. Baseline characteristics are reported in Table 16. Of note, all participants were female, reflecting the midwifery

student population. The majority of participants were aged between 18-24 years (61%), with 13 (31.7%) and three (7.3%) participants in the 25-34 year and 35–45-year age categories, respectively. Twenty-eight (68.3%) participants were enrolled in the BSc midwifery programme and 13 (31.7%) participants in the Higher Diploma midwifery programme. The majority of participants (82.9%) had previous experience with VR. Of these, twenty-five (61%) participants had previously used VR during a previous research project, nine (22%) participants had played recreational games with a VR headset, and one (2%) participant reported owning several VR headsets for personal gaming.

Table 16 Baseline characteristics for the midwifery student study cohort (n=41)

Characteristics	Number (%)
Age (Kaka et al.)	
18-24	25 (61%)
25-34	13 (31.7%)
35-45	3 (7.3%)
Gender	
Male	0
Female	41 (100%)
Programme	
BSc Midwifery	28 (68.3%)
Year 3	10
Year 4	18
Higher Diploma Midwifery	13 (31.7%)
18 Months	13
Previous Virtual Reality experience	34 (82.9%)

Repeated measures ANOVA revealed no statistically significant difference in knowledge scores between time points $F(2, 39) = 5.15$, $p = 0.77$. Mean scores and standard deviations are displayed in Table 17.

Table 17 Mean multiple-choice questionnaire scores at time points 1-3 (n=41)

Time period	Mean (SD)*
1 (Pre-intervention)	8.05 (0.95)
2 (Post-intervention)	8.15 (1.22)
3 (1-week follow-up)	8.00 (1.27)

*Values reported are mean (standard deviation (SD)).

With regard to the secondary outcomes evaluating the participants' attitudes and opinions towards the VRLE, participants rated the VRLE highly, with a mean score of 69.73 (SD 6.81). Results of the SCLS are reported in Table 18.

Table 18 Student Satisfaction in Learning and Self Confidence Scale (SCSL) scores for participants using the VRLE (n=41)

Scale	Mean (SD)
Total SCSL Score	69.73 (6.81)
Satisfaction in Learning	23.07 (3.24)
Self-Confidence in Learning	37.24 (3.02)

The Students' Satisfaction in Learning and Self-Confidence Scale is a 13-item instrument Likert-style scale with scores ranging from 1 = strongly disagree to 5 = strongly agree. It is divided into two subscales, satisfaction in learning and self-confidence in learning. Maximum score is 75 and minimum score is 15.

VRDS mean item score per section are reported for each design feature in Table 19. Objectives and information (4.72) and support (4.85) were rated the highest among the design features. In reference to fidelity and resemblance to real life, participants also reported high levels of realism (4.54). This adds to the face and content validity of the VRLE as a learning tool.

Table 19 Virtual Reality Design Scale scores (VRDS)

Questionnaire Item	Mean Item Score
Objectives & Information	4.72
Support	4.85
Problem Solving	4.76
Feedback	4.68
Fidelity (Realism)	4.54

VRDS is an 18-item instrument to rate the design of the VRLE with scores ranging from 1 = strongly disagree to 5 = strongly agree.

Table 20 describes the side effects experienced by participants in the intervention group. The most commonly reported side effects were dizziness in 20 (49%) participants, any symptoms similar to motion sickness in 13 (32%) participants, and disorientation in 12 (30%) participants.

Table 20 Virtual Reality Learning Environment side effects experienced by participants

Side Effect	Number affected (%)*
Eye or muscle twitching	0 (0%)
Increased salivation	0 (0%)
Drowsiness	1 (2%)
Impaired hand-eye coordination	2 (5%)
Excessive sweating	2 (5%)
Fatigue	2 (5%)
Discomfort or pain in the head or eyes	3 (7%)
Involuntary moving	3 (7%)
Loss of awareness	3 (7%)
Impaired balance	6 (15%)
Eye strain	6 (15%)
Blurred/Altered or Double vision	6 (15%)
Light-headedness	7 (17%)
Nausea	8 (20%)
Headache	10 (24%)
Disorientation	12 (30%)
Any symptoms similar to motion sickness	13 (32%)
Dizziness	20 (49%)

*Percentage values calculated from overall intervention group size (n=41). Participants completed a questionnaire on the side effects experienced during the VRLE.

The number of symptoms reported by each participant are represented in Table 21. Nine (22%) participants reported no symptoms during the intervention, whereas 18 (44%) participants experienced one to two symptoms, eight (20%) participants experienced three to four symptoms, and six (15%) participants experienced five or more symptoms.

Table 21 Total number of symptoms experienced by participants

Number of symptoms	Number affected (%)*
No symptoms	9 (22%)
1 to 2 symptoms	18 (44%)
3 to 4 symptoms	8 (20%)
5 or more symptoms	6 (15%)

*Percentage values calculated from overall intervention group size (n=41).

4.4.2 Qualitative analysis

The themes identified during the analysis include “Learning in 3D”, “The Power of Visual Learning”, “The value of Educational Technology”, and “Learning can be fun and enjoyable”.

Learning in 3D

In response to being asked about the incorporation of VR headsets into the classroom, the majority of participants favoured the addition of VR as an educational tool.

> *“[VR would be] extremely beneficial for students to help learn about fetal positions and lie. When we began the H Dip in midwifery, I found them really difficult concepts to grasp, and this experience would have been a great lab to help learn.”* [P23] (H Dip = Higher diploma midwifery programme).

However, the side-effects experienced by some participants appeared to be a limiting factor.

"…it made me feel 'car sick', may not be suitable for all." [P39]

Lastly, while students in this study largely appreciated the benefits of VR, reservations were expressed by some students regarding the widespread implementation of VR as an educational tool due to the side effect profile.

"…. Personally, I did not enjoy it because the experience made me feel sick. Not a suitable learning tool for me. I can see how others would find it beneficial." [P2]

"I think they would be useful occasionally but not used with everything as it is very disorienting." [P13]

The Power of Visual Learning

Students in this study also appeared to value the benefit of the 3D learning experience in the context of aiding the visual learner.

"…. I am a visual learner and found this virtual reality experience very helpful to learn about the different presentations. I would have loved to have been able to use this tool to aid my learning in school/college" (participant info) and

"*I find visual aids very helpful when studying so that was really good." [P31]*

The Value of Educational Technology

Students in this study highlighted the positive contribution of the VRLE to their understanding of the topic.

"…. Wish this is how I learnt this topic in first year - it's a difficult one to visualise and I feel like there would have been less confusion with a learning tool like this." [P1]

Interestingly, students also highlighted additional topics for which VRLEs could be utilised and identified to provide potential future benefits within midwifery education.

> *"Keen to see a LSCS (Lower segment caesarean section) interactive VR and emergency simulations."* [P32]
>
> *"…. see animations of the mechanism of labour, to fully utilise the advantages that VR offers."* [P6]

Coupled with the benefit of visual learning, students in this study also identified the value added by this educational tool in terms of patient safety.

> *"…. I think it's a fantastic idea, especially for visual and kinaesthetic learners. One issue in healthcare education is that we are often told as students "you won't understand this until you see it in practice" - VR could allow students to experience things as though in person without learning skills and concepts for the first time at a patient's [woman's] bedside."* [P6]

Another point raised by students in this study was in relation to the reduced number of students allowed on clinical sites due to the global pandemic Covid-19, thus limiting exposure to the clinical environment and highlighting the benefits of utilising VR as an additional learning opportunity.

> *"…...I feel it would be very useful particularly at the minute where it might not be possible to have large numbers of students on clinical sites."* [P4]

Learning can be a fun and enjoyable

Overall, students reported enjoying the learning experience facilitated through the VRLE, describing the experience as *"…. extremely interesting, would love to do more"* [P27]*,* and appreciating that it was a *"very fun, good way of learning."* [P8]

4.5 Discussion

This study is the first documented investigation, that I am aware of that assesses the effectiveness of a VRLE in midwifery education. I developed and implemented a novel and innovative educational tool consisting of a VRLE on the topic of "*fetal lie, position, and presentation in pregnancy"*. Similarly to Chapter 3, the VRID model, provided a structured process in the development of the VRLE and a conceptual framework based on experiential learning theory and constructivism guided the lesson plan and learning objectives. Although the VRLE did not change knowledge levels of participants in this study, the learning experience was highly rated by students. Additionally, higher levels of engagement and enhanced understanding of fetal and pelvic anatomy were self-reported and not formally assessed, due to timing constraints and COVID-19 safety protocols. However similarly to the discussion in Chapter 3, it must be acknowledged that the integrative goals of VR did not align with the learning outcomes. Understanding of 3D structures was not assessed in the MCQ utilised in this study. This is a limitation of the study which is discussed further below. The aim of this cohort study was to Similar findings are reported in the literature with previous studies testing VR in medical student education reporting student knowledge levels improving or remaining unchanged (Maresky et al., 2019a, Moro et al., 2017b). These studies also demonstrated enhanced clinical reasoning skills and higher levels of satisfaction (Wang et al., 2020, Berg and Steinsbekk, 2020, Liaw et al., 2014). This reflects the findings in our study of midwifery students, which contribute to the growing body of evidence in the area (Hardie et al., 2020).

Research on the use of VRLEs is lacking within the field of Midwifery education. I chose the topic of "*fetal lie, lie position and presentation in pregnancy*". It is a topic in the subject of anatomy and embryology which can be quite difficult for students to comprehend, as it requires the understanding of 3D structures and processes. The current literature supports the use of VRLEs to enhance the understanding of complex concepts that require 3D visualisation (Zhao et al., 2020). Midwifery students are required to understand the anatomy of the fetal head in relation to the maternal pelvis in preparation for birth. Findings from our thematic analysis suggest that learners find "VR Baby" a helpful learning tool to enhance understanding of this topic. The use of our VRLE to teach complex 3D anatomical structures to Midwifery students is novel and an important contribution to the growing body of evidence within this discipline.

Results of the MCQ assessment showed no increase in levels of knowledge or levels of knowledge retention. Interestingly, this finding is also reflected in our systematic review. Our study population included students who had completed university-based lectures on the topic of fetal lie, position, and presentation in pregnancy, so that all students had the same level of theoretical knowledge. VR learning tools are thought to support learning and enhance understanding by building and constructing knowledge based on prior knowledge. This is a principle of constructivism which is thought to support VR. That is why a population with a baseline knowledge of the topic was selected. Whilst the assessment did not evaluate student understanding of 3D structures, it did evaluate knowledge which is an important contribution to research in this area.

Secondary outcomes reflect a positive learning experience among participants. This study finding is consistent with our study findings from our RCT presented in Chapter

3 and the current literature (Wang et al., 2020). This finding suggests that VR learning tools provide a fun and engaging learning environment that enhances student satisfaction and self-confidence with the learning material. As discussed previously learner opinions and attitudes towards learning are an important factor for educators when developing learning tools (Kay and Kibble, 2016). Furthermore findings from our thematic analysis also favour the use of VR learning tools despite a high incidence of side effects in this study population.

Cybersickness is a condition that results in a variety of symptoms including nausea, disorientation, discomfort, headaches, fatigue, difficulty concentrating, and problems with vision (Servotte et al., 2020a). This is a limitation of VRLEs. Similarly to the RCT, in this study almost half of the participants using the VRLE experienced dizziness and symptoms similar to motion sickness. However despite the side effects experienced by the participants, high scores reported on the SCLS reflect a positive attitude towards the VR learning tool. Side effects of VR learning tools are poorly reported or assessed in the literature (Kyaw et al., 2019d). The reporting of side-effects is an important contribution to the growing body of research on VR learning tools (Baniasadi et al., 2018, Servotte et al., 2020a). With the advancement of technology, the side effect profiles are constantly improving with newer models of VR headsets, which may reduce this limitation in future studies.

It is important to note, however, that VR technology is not intended to replace standard learning and teaching modalities but to enhance it as an educational tool. The literature has already suggested the benefits of VR providing a safe environment for practice in trauma or natural disaster situations (Mills et al., 2019, Ingrassia et al., 2015, Rossler et al., 2019a). In addition, VRLEs encourages deep learning which is thought to

promotes long-term understanding in contrast to short term rote learning and memorisation (Kyaw et al., 2019d, Pottle, 2019, Padilha et al., 2019a, Pahuta et al., 2012). For students who prefer multichannel learning methods, VRLEs can facilitate a learning environment that promotes self-constructed knowledge acquisition, which in turn encourages knowledge reinforcement and intrinsic motivation to learn which benefits students as future clinicians (Sun et al., 2019).

4.5.1 Strengths and Limitations

To our knowledge, this is the first VRLE developed as an educational tool designed to enhance the understanding of complex concepts such as fetal and pelvic anatomy. Three-dimensional visualisation techniques help to improve the understanding of complex anatomical structures, in addition to some learners benefiting from multichannel approaches (Sun et al., 2019). I used the same instruments to evaluate learning objectives in an effort to contribute to the use of a standardised instruments to evaluate learning objectives related to immersive technology.

The authors note that the findings of this study are limited due to a small sample size from a single setting in addition to the short time period between MCQ 2 and MCQ 3 i.e., 1 week. An RCT was not carried out due to time and resource limitations. Participants were recruited from both the penultimate and the final years of the Midwifery programmes, and all had a baseline knowledge of the topic. This may have influenced the high pre-intervention scores. Perhaps future research should focus on assessing student knowledge and understanding of 3D structures at an earlier stage in training.

Furthermore I note that the primary outcome assessed increase in knowledge levels. Similarly to the RCT, on reflection the strength of VRLEs lie in their ability to enhance

3D understanding of complex objects and structures such as those found within the subject of anatomy and embryology. This author acknowledges that the strengths of the VRLE were not aligned to the learning objectives and the MCQ assessment. Knowledge assessment is an important component to evaluate the educational effectiveness of a VR learning tool. On reflection, the MCQ knowledge assessment did not assess one of the integrative goals of VR i.e. student understanding of 3D structures. An assessment that included questions on spatial relations and understanding of 3D structures could have assessed this integrative goal more appropriately. However future studies should incorporate assessment of spatial awareness coupled with factual knowledge.

4.6 Conclusion

In conclusion, this study explored the effectiveness of a VRLE to educate midwifery students. The findings demonstrate that VRLEs can provide a learning experience that increases students' self-confidence and satisfaction with learning. Virtual reality has been around for decades; however, the use of virtual reality technology in midwifery and nursing education is still in its infancy today.

Chapter 5 A Cost Analysis of a Virtual Reality Learning Environment Versus a Traditional Tutorial to Teach Medical Students about Fetal Development for Obstetrics and Gynaecology Education

Manuscript under review with Medical Teacher: G Ryan, J O'Mahony, M Higgins, E Mangina, F McAuliffe. A Cost Analysis of a Virtual Reality Learning Environment Versus a Traditional Tutorial to Teach Medical Students about Fetal Development for Obstetrics and Gynaecology Education

5.1 Summary

5.1.1 Background

There is a dearth of evidence on the cost of virtual reality learning environments (VRLEs) within medical student education.

5.1.2 Objective

To compare the cost of two educational tools, a VRLE and a didactic tutorial on the topic of "*Stages of fetal development in pregnancy*" to teach medical students within a university Obstetrics and Gynaecology module.

5.1.3 Methods

This study was carried out as part of the randomised controlled trial with medical students presented in Chapter 3, comparing the effectiveness of a VRLE and a didactic tutorial on the topic "*Stages of fetal development in pregnancy*". The intervention group underwent a lesson in a VRLE, and the control group underwent a tutorial with a PowerPoint presentation on the same topic. The primary outcome was differences in post intervention knowledge scores of the two groups at two time-points: immediately after the lesson (Multiple choice questionnaire - MCQ 2) and one-week later (MCQ 3). I conducted a cost analysis from the perspective of the University under two scenarios: during COVID-19 and outside of COVID-19. The costs of the two educational tools were measured in conjunction with post intervention knowledge scores as measures of educational effectiveness. A sensitivity analysis was carried out for best-case worst-case scenario of the cost of the tutor.

5.1.4 Results

The operating costs of the VRLE, during COVID-19 and outside of COVID-19 was €131.82 and €81.47, respectively. The cost of the online tutorial during COVID-19 and outside of COVID-19 was €42.72. The cost per QASE of the VRLE during COVID and outside of COVID was €1.76, and €0.70 during the online tutorial in both scenarios. The VRLE was more costly than the didactic tutorial in a case of simple dominance. For the VRLE, the operating cost per learner was €6.28 and €3.88, during COVID and outside of COVID-19, respectively, compared to €2.14 for the didactic tutorial under both scenarios. Break-even analyses revealed the lower costs of the VRLE, including a reduction in price of the VR headsets, and hygiene parameters were required to make it equal to the didactic tutorial and the cost of the tutor to break-even. Sensitivity analyses revealed the best-case worst-case scenario based on the cost of the tutor.

5.1.5 Conclusions

The VRLE results in better knowledge retention and is more cost effective than a didactic tutorial. VRLEs can be considered as costly educational tools.

5.2 Introduction

The advancement of technology and increase in market demands have led to the wide-spread availability and affordability of educational technologies for educational institutions (Walsh et al., 2020). In order to incorporate virtual reality (VR) into the health science curricula, economic analyses are required to inform relevant stakeholders (Maloney et al., 2019).

Several systematic reviews demonstrate the effectiveness of VR in healthcare education. They also highlighted the lack of evidence on the associated costing of the implementation of VR in healthcare education (Kyaw et al., 2019c, Zhao et al., 2020). A recent meta-analysis studied the effectiveness of VR to teach anatomy. It included 15 RCTs that concluded VR to be an effective way of improving learners' knowledge (Zhao et al., 2020). Another scoping review of VR and its applications in healthcare education revealed that VR, as a complementary method to medical education, plays an important role in improving the performance of different medical groups (Samadbeik et al., 2018).

A systematic review and meta-analysis carried out by the Digital Health Collaboration also found similar findings that VR improved knowledge retention and skills (Kyaw et al., 2019b). It is important to note that, of 31 RCTs, only one study included a formal cost-analysis component of VR. This study compared the cost of a VR tool; a VRLE and traditional paper floor plans to help incoming new nursing employees to find their way around the hospital. The VR tool was more expensive to develop but provided greater value during implementation by reducing staff time for practicing wayfinding in the hospital (Halfer and Rosenheck, 2014). A recent targeted systematic review carried out by Hippe (2020) investigated the general cost analyses in medical

simulation-based training and a more focused search on cost analyses in neonatal resuscitation training. Search terms included “training, “education”, “high-fidelity simulation”, “virtual reality”, “low dose, high frequency”, “cost analysis, “ and “cost-effectiveness” (Hippe et al., 2020). MEDLINE and PubMed databases were searched using the above-mentioned search terms. Seven articles were identified that carried out a cost analysis on some form of simulation-based healthcare (Hippe et al., 2020). Across the two queries, eight articles on VR based training including a cost-analysis were identified. Interestingly, most studies in the search related to Surgical and Obstetrics and Gynaecology training specialties. Of these eight articles, the most recent was carried out in 2015; most articles pertain to resident (postgraduate setting) training programme. With regard to cost analyses, seven of these refer to costings of the programme with only one article carrying out a formal cost-effectiveness analysis (Isaranuwatchai et al., 2014) and four that carried out general cost analysis with no detail as to what specific type of analysis (Orzech et al., 2012, Raque et al., 2015, Danzer et al., 2011, Lewis et al., 2011). This reflects the lack of cost analyses in the published literature and a standardised approach to carrying out cost analyses in medical education (Walsh et al., 2020).

As evidenced above, the costing of VR tools within medical education, especially at undergraduate university level is somewhat limited. Within medical education, there has been a long-standing belief that money should be invested in medical education to reduce poor patient outcomes and improve delivery of healthcare systems (Zendejas et al., 2013). The cost and value of teaching and learning practices in medical education is expensive. In the UK, the cost of educating a medical student is approximately £230,000 (Department of Health, 2017); globally, the estimated annual spend is more than £63 billion (Walsh et al., 2013). Costs have a direct impact on the

accessibility of education, the efficiency and quality of education, and the productivity of our health workforce (Zurn et al., 2004, Kremer et al., 2014). Therefore, research on this topic should include a cost-analysis component so that relevant stakeholders can be better informed when allocating funding.

From the published literature, there is a wealth of information and guidelines on cost analyses in relation to healthcare economics (Information and Authority, 2020). However, there is no universal consensus on how to report cost analysis in medical education (Baker et al., 2016). There are several issues that make costing medical education a challenge, as outlined by Walsh (2013). These include establishing direct and indirect costs, the issue of defining educational effectiveness and the ambiguity of definitions pertaining to the nomenclature surrounding cost analysis research (Walsh et al., 2013). Therefore, costing in medical education has been poorly reported or evaluated until now. The Academy of Medical Educators in Europe (AMEE) recently published a guide to conducting cost analyses in health professions education (Foo et al.) in an effort to provide transparency and efficiency in cost analyses, coupled with a guide for researchers in the area of medical education who may be economic novices (Foo et al., 2021).

Furthermore, the COVID-19 pandemic impacted the education of millions all over the world in 2020. The way in which we were teaching medical education changed overnight to online learning, which led to immediate need for innovative and dynamic approach for learning (Gordon et al., 2020). For example, at our institute, we developed an online curriculum for Obstetrics and Gynaecology over a two-week period for the summer semester of medical students undertaking their Obstetrics and Gynaecology placement. Immersive technologies are a logical and viable response to

this situation (Remtulla, 2020). The uncertainty of global pandemics and potential for more in the future suggest that alternative and additional learning tools should be made accessible for students. With the advancement of technology and reduction in costs of VR tools, it is worth exploring the potential of students using more immersive technologies to enhance the learning process. With an increasing amount of content being developed for virtual patient simulation and clinical scenarios, this has great promise for learning from home in certain circumstances (Remtulla, 2020). For example, long distance learning and global pandemics. The impact of costs on various educational tools is becoming a recognised factor in medical education costs. Studies incorporating cost analyses can act as a tool to support decision making for stakeholders so that funds may be utilised appropriately.

I conducted a cost analysis of the VRLE that was developed and used for the medical student RCT and midwifery cohort study, described in Chapter 3 and 4, respectively. Therefore, the purpose of this cost analysis was to provide an insight into the cost of alternative teaching tools in an Obstetrics and Gynaecology module for medical students in University College Dublin, Ireland. The cost analysis was carried out in accordance with national and international guidelines provided by the Health Information and Quality Authority in Ireland (HIQA) (Information and Authority, 2020) and AMEE (Foo et al., 2021).

5.3 Study Design and Methods

A cost analysis was conducted as part of the RCT, which compared achievement of expected learning objectives by medical students using a VRLE versus didactic tutorial. The research question is “how much does it cost to conduct this activity?”. This analysis was conducted under two scenarios, firstly the conditions of the RCT

presented in Chapter 3 i.e., the study was conducted during the global pandemic COVID-19, and, secondly, the study conditions outside of COVID-19. A cost analysis was chosen, as it allowed comparison of the cost of two alternative learning tools that can be considered equally effective.

5.3.1 Randomised controlled trial

To summarise briefly, the RCT compared the effectiveness of a VRLE with a traditional didactic tutorial to teach medical students the topic of "*Stages of fetal development in pregnancy*". The primary outcome measure was differences in knowledge scores immediately post (MCQ2) intervention and one week later (MCQ3). Secondary outcomes assessed students' attitudes and opinions of the learning experience via validated Likert-style questionnaires, namely the Student Satisfaction and Self-Confidence in Learning Questionnaire (SCLS) and a VR design questionnaire (intervention group only), which also evaluated the side effect profile of the VRLE. The main finding in the RCT is that there is no significant difference in knowledge gain between the two learning tools.

5.3.2 Results of the randomised controlled trial

Results from the RCT are presented in detail in Chapter 3, Section 3.4.

5.3.3 Economic evaluation

Based on the RCT as outlined above, I sought to perform a cost analysis to compare two educational tools, a VRLE and a traditional tutorial for medical students at University College Dublin, where cost is measured from the perspective of the university. The study was conducted as recommended by guidelines for the Economic Evaluation of Health Technologies in Ireland (Information and Authority, 2020), AMEE

(Foo et al., 2021), and in accordance with the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) economic checklist (Husereau et al., 2013).

The economic analysis was carried out as follows. Firstly, I identified the resources used to develop and implement the two learning tools across three main categories: personnel, facilities, and equipment. I used Levin's "*Ingredients Method*" (Levin and Belfield, 2015) to capture and categorise the costs involved to develop and run the two educational tools under the two study conditions during COVID-19 and outside of COVID-19. The development costs included any costs that were involved in the development of the VRLE and the online tutorial such as the tutor. The running costs (also referred to as the operating costs) include all costs required to ensure the running of the VRLE and the tutorial such as the teaching room. The breakdown of resources used for both learning tools is outlined in Table 22 below.

Table 22 Breakdown of learning tool and associated resource consumption by category

VRLE				
Phase	**Activity**	**Personnel**	**Facilities**	**Equipment/ materials**
Development	Design module content	Researcher; Computer science student		Computer
	Make 3D models			
	Create online environment	Computer scientist		Software licence Oculus quest VR headset
Training	Tutor to learn how to use VR headset and create instructions for participants	Tutor	Lecture room Hygiene products	VR headset/Laptop Print instructions guide
Tutorial				
Phase	**Activity**	**Personnel**	**Facilities**	**Equipment/ materials**
Development	Design module content	Researcher/Tutor	Lecture room*	Computer
Training	N/A			

*Denotes the resource was required outside of COVID-19

The next step involved defining the specifications of the resources by category, which are clearly described in Table 23.

Table 23 Resource item specifications grouped by category

Category	Resource item	Specification	VRLE*	OT*
Personnel	Researcher/Tutor	Postgraduate MD Student/Tutor	✓	✓
	Computer Science Student	Final Year Undergraduate Student – VRLE development carried out as part of final year project	✓	
Facilities	Education/tutorial room/office space	Teaching room	✓	✓
Equipment/ materials	Computer software	Opensource free software	✓	
	VR Headset	Oculus Quest VR headset Sourced DCB Group Ltd	✓	
	Hygiene products	Masks; Hand sanitiser; Anti-microbial wipes	✓#	
	Computer	Laptops to develop tutorial and perform tutorial (online due to covid19) – personal student/tutor laptops	✓	✓
***VRLE = Virtual Reality Learning Environment, OT = Online Tutorial** **#Not all required outside of COVID-19 environment**				

Table 24 outlines the volume of each resource that was used during the development and implementation of the learning tools.

Table 24 Volume consumed and measurement method for resource items

Resource item	VRLE		Tutorial	
	Measurement method	**Volume**	**Measurement method**	**Volume**
Researcher/Tutor	Log of working hours for study	140 hours	Log of working hours or study	4hours
Computer science student	Log of working hours for study	128 hours	n/a	
Teaching room	Based on learning experience activity	10.5 hours (30mins x 21 participants =630mins)	Space for development and online tutorial (1hr x20 students)	4hours
VR Headset x3	Invoiced volume	3	n/a	
Computer Software	Opensource	free	n/a	
Computer	Dell €530			

Following this, I assigned prices to each resource item seen in Table 25. Costs were then calculated for both learning tools and then sub-grouped, based on whether they are development costs and therefore only incurred once, or if they are operating costs and would therefore be incurred if the learning tools are available yearly. The cost for the VRLE tool is outlined in Table 26 and the costs of the VRLE outside of COVID-19 are outlined in Table 27. The cost of the online tutorial is outlined in Table 28. If the tutorial were to take place in the university pre- or post-COVID19, the cost would also

include the rental price of a lecture room or tutorial room. To calculate the rental price of the room, student services in the university were contacted for a quote. The costs of conducting a tutorial pre- and post-pandemic are outlined in Table 29.

Table 25 Price and pricing method for resource items

Resource item	Pricing method	Price	Adjusted price
Researcher	HIQA Guidelines for the Economic Evaluation of Health Technologies in Ireland Point 2 of clinical tutor scale	€30.22hr	n/a
Computer Science Student	N/a part of final year project	n/a	n/a
VR Headset	Invoice (DCB# group Ltd)	€599.99 per unit	
Teaching room	University space to rent per day based on an 8-hour working day	€100/day	12.50/hr
Computer Software Unity3D* / 3D Slicer	Free opensource software online version	n/a	n/a
Laptop	Dell	€530	n/a

***3D= three dimensional**

#DCB group = IT reseller service in Ireland where headsets were sourced.

Table 26 Summary of VRLE costs during COVID-19

Category	Resource	Description	Volume	Price	Cost
Personnel	Clinical Tutor Point 2	Development costs	140hrs	€30.22/hr	€4230.80
	Clinical Tutor Point 2	Teaching	0.17hrs	30.22/hr	€5.14
	Computer Science Student	4-year degree	128hrs	n/a	0
Equipment/ materials	Software	Opensource	Free	n/a	0
	Computer				€530.00
	Teaching room		2	€12.50/hr	€25
	Oculus Headset	VR Headset device	3	€599.99	€2.00
	Hand gel		3	€9.45	€28.35
	Masks		1	€22.00	€22.00
	Antimicrobial wipes		1	€9.43	€9.43
				Development costs	**€4760.8**

Category	Resource	Description	Volume	Price	Cost
				Operating costs	**€131.92**
				TOTAL	**€4892.72**
				Total per learner	**€232.99**
				Operating cost per learner	**€6.28**

Table 27 Summary of VRLE costs outside COVID-19

Category	Resource	Description	Volume	Price	Cost
Personnel	Tutor	Clinical tutor Point 2	140	€30.22	€4230.80
	Tutor		0.17	€30.22	€5.04
	Computer Science Student	4-year degree hours	128	n/a	0
Equipment/ materials	Software	Opensource	Free		0
	Computer	Unit	1	€530	€530
	Teaching room	Hours	2	€12.5	€25
	Oculus Headset	VR Headset device	3	€599.99	€2.00
	Antimicrobial wipes		1	€9.43	€9.43
				Development costs	**<u>€4760.80</u>**

Category	Resource	Description	Volume	Price	Cost
				Operating costs	**€81.57**
				TOTAL	**€4842.37**
				Total per learner (21)	**€230.59**
				Operating cost per learner	**€3.88**

Table 28 Summary of Online Tutorial costs

Category	Resource	Description	Volume	Price	Cost
Personnel	Tutor	Postgraduate MD candidate	3	€30.22	€90.66
	Tutor	Teaching time	1	€30.22	€30.22
Facilities	Lecture room	Room for tutor to teach students	1	€100	€12.50
Equipment/ materials	Desktop	Develop tutorial and host tutorial	1	€530	€530
				Development costs	**€620.66**
				Operating costs	**€42.72**
				TOTAL	**€663.38**
				Total per learner	**€2.14**

Table 29 Summary of Traditional Tutorial costs outside of COVID-19

Category	Resource	Description	Volume	Price	Cost
Personnel	Tutor	Postgraduate MD candidate – researcher/specialist lecturer	3	€30.22	€90.66
	Tutor	Teaching	1	€30.22	€30.22
Facilities	Lecture room	Room to teach students	1	€100	€12.50
Equipment	Computer	Dell	1	**€530**	**€530**
				Development costs	**€620.66**
				Operating costs	**€42.72**
				TOTAL	**€663.38**
				Total per learner	**€2.14**

Finally, I carried out a deterministic sensitivity analysis with best- and worst-case scenario in relation to the various scenarios associated with the cost of employing a clinical tutor based on the current pay scale shown below.

5.4.1 Cost analysis

Regarding the results, I will firstly report the results of the cost analysis under the study conditions i.e., RCT during COVID-19, followed by the results of the cost analysis

under alternative conditions i.e. outside COVID-19. Table 23 above, describes the details of the personnel, facilities, and equipment used to develop and implement the two educational tools. Also mentioned above, Tables 26 and 28 summarise the cost of the two learning tools during COVID-19. Under the study circumstances of COVID-19, the development cost of the VRLE is €4760.80 and the operating cost is €131.82. The development cost of the online tutorial is €620.66, and the operating cost is €42.72. The total cost per learner is €6.28 for the VRLE, compared to €2.14 for the tutorial.

If the study were to take place outside of COVID-19 pandemic public health guidance (i.e., without social distancing and restrictions in student numbers), Tables 27 and 29 summarise the cost of the two learning tools outside of COVID-19. Under these circumstances, the development cost of the VRLE is the same, at €4760.80, but the operating cost is lower at €81.47. This is largely due to the reduced amount of hygiene products required. The development and operational costs of the traditional tutorial remain the same at €620.66 and €42.72, respectively. With regard to the cost outside of COVID-19, the VRLE was still more expensive to run. The total cost per learner is reduced, compared to the previous case in our study at €3.88 for the VRLE and €2.14 for the tutorial.

5.4.2 Sensitivity Analysis

A one-way sensitivity analysis was also carried out of the best- and worst-case scenario in relation to the cost of employing the teaching staff. For this study, the clinical tutor was employed at point 2 of the salary scale, therefore the costs were re-calculated using the salary scale of a clinical tutor as a best-and worst-case scenario. This meant the best-case scenario would be employing a clinical tutor at point 1 of the

salary scale and, worst-case scenario, employing a tutor at point 6 of the salary scale, respectively. The results are demonstrated in Table 30.

Table 30 Sensitivity analysis carried out of the best- and worst-case scenario in relation to the cost of employing a clinical tutor during COVID-19

	VRLE*			Online tutorial		
	Best case	**Original**	**Worst case**	**Best case**	**Original**	**Worst case**
Tutor hourly rate	€29.10/hr	€30.22/hr	€34.26/hr	€29.10/hr	€30.22/hr	€34.26/hr
Tutor cost	€4078.85	€4235.84	€4802.11	€116.40	€120.88	€137.04
Total cost	€4735.63	€4892.62	€5458.89	€658.90	€663.38	€679.54

*VRLE: virtual reality learning environment

5.5 Discussion

This study was carried out with the aim of analysing the cost of two educational tools based on the RCT, a VRLE and an online tutorial within an Obstetrics and Gynaecology module of a university medical degree programme. The educational learning tools had known learning objectives evaluated through the RCT presented in Chapter 3. In both cases, during COVID and outside of COVID, the VRLE is more costly. The traditional tutorial and the online tutorial are equal in cost under both conditions.

Due to the global pandemic COVID-19, the tutorial took place with government guided restrictions, meaning that strict precautionary measures were used in line with public health guidance and government restrictions to facilitate the running of the trial. Only one or two students were permitted to enter the teaching room at a time in line with COVID-19 government guidance. Timings were spaced out and the lecture room was used for a longer period to facilitate cleaning of the VR headsets. Interestingly, when the analysis was conducted for the alternate scenario, the costs remain the same for the tutorial (€2.14 per learner). It is important to note that transport and time costs are not included from the perspective of the student for the traditional tutorial that requires the student to be on university premises. The additional expense of the VRLE is less outside of COVID-19 due to the reduction in hygiene requirements Outside of COVID19, the tutorial would be a less costly option compared to the VRLE, with a total operating cost of €42.72 and total cost per learner of €2.14. However, once the VRLE is developed it can be used repeatedly without the development costs.

Innovative educational technology and cultural change within the classroom means that alternative immersive educational tools are being utilised more frequently

(Remtulla, 2020). In addition, the global pandemic COVID19 saw medical education change to an online delivery system overnight, which highlights the need to embrace innovative and novel educational tools now more than ever (Gordon et al., 2020). Furthermore, students in clinical years had automatic reduced clinical time with patients. In the future, there may be other situations or occasions where VR may be a more suitable educational tool in the case of reduced clinical exposure, a safer environment for students to develop skills without fear or pressure of making a mistake and causing potential harm to students.

I have already discussed how research is demonstrating VR to be an effective method of supporting teaching in technical and non-technical skills within medical education from the use of virtual patients, VRLEs for complex topics, and VR surgical simulators (Masters et al., 2016, Kyaw et al., 2019a). VR can provide an alternative educational experience in a safe and controlled environment for medical students to practice clinical skills without a risk to patients, enhance the understanding of complex concepts (Walsh et al., 2020). Although they are still more costly than traditional learning tools, with the advancement and availability of such technology they may become cheaper over time, however. There has been an increased financial challenge from rising healthcare costs, which is a prominent consideration in medical education today (Bergin and Horgan, 2020). Medical education in Ireland, like many other countries, share the common challenge of providing high-quality learning capable of producing graduates fit for modern-day medical practice. This is also dependent on funding from a variety of sources including the university and affiliated hospitals (Humphreys, 2008). Therefore, cost analyses provide a helpful guide for supporting decision-making in medical education for relevant stakeholders. There has been a call for more robust evidence on the use of immersive educational tools that incorporates

a cost analysis component (Walsh et al., 2020). This study adds to further current research on the costs of VR as an education tool in medical education.

5.5.1 Limitations

This cost analysis was carried out in an effort to compare the cost of two alternative educational tools. This author acknowledges that there are limitations to the study as follows. During the costing of the two educational tools, bias may be present due to the unavailability of definite costs for some resources which may have resulted in inaccurate costings. This study is restricted to the educational tools developed for a specific module in an undergraduate medical degree programme for the RCT. The development of the VRLE was part of a final year project, which contributed to an overall grade for the computer science student. In the future, a skilled graphic designer may be required to develop more lessons or content for the VR headsets, which would increase the cost of the product. Equally, it is possible that, as there is an increase availability of interactive content in the market, this may lead to the free availability of universal content. Another limitation is the potential inaccuracy of some of the costings such as the lecture room, which was calculated based on rough estimates provided by the university events department. Furthermore, due to limited data on VR headsets, it is difficult to calculate the depreciation, as the lifespan is unknown. Similar to mobile phones they require regular software updates; for the purpose of this study, we estimated a lifespan of five years for the VR headsets. Furthermore, future studies should include scale up of costs to assess the long-term cost benefits of using such learning tools.

5.6 Conclusion

In summary, this cost analysis adds to the current evidence base on the use of VR in medical education. These study settings explored the cost of a VRLE and an online tutorial during COVID-19 and outside COVID-19. The VRLE resulted in a more costly approach to teaching on the topic of “Stages of fetal development”. This study adds to research in this area. The advancement of educational technology and the recent global pandemic COVID-19 is providing alternative pedagogical tools. There is increasing use of these learning tools however further cost analyses are required to assess the long-term cost benefits and effectiveness of VRLEs in medical education.

Chapter 6 “VR Baby” Development of VR Congenital Abnormalities for Patient Education

6.1 Summary

6.1.1 Objective

Virtual reality (VR) is a potentially beneficial tool for antenatal patient education and can enhance the understanding of complex congenital abnormalities. I will describe the development of three-dimensional (3D) fetuses with congenital abnormalities and present a pilot case study as a proof of concept for a future research project.

6.1.2 Study design

Institutional ethical approval was obtained to collect MRI images and develop VR models of congenital abnormalities for a patient education case series. The primary outcome is patients' attitudes and opinions of the 3D models and perception of maternal attachment assessed via a questionnaire.

6.1.3 Results

Three VR models of congenital anomalies were developed. One pilot case study was conducted, using a 3D model of a congenital diaphragmatic hernia model. Results from the questionnaire revealed an overall positive experience with the 3D models

6.1.4 Conclusion

3D models of congenital abnormalities were developed and tested in a pilot case study, which demonstrated the potential of VR as an educational tool for patients.

6.2 Introduction

A diagnosis of a congenital anomaly is a complex and challenging diagnosis for parents in the antenatal period. In an annual report, carried out by The National Congenital Anomaly and Rare Disease Registration Service in England (NCARDRS), it reports the prevalence of congenital anomalies to be 1 in 47 births (Stevens and Platt, 2018). Such diagnoses require sensitive and multidisciplinary team (MDT) input by clinicians. For parents, it is a time of difficulty and uncertainty. Understanding of the abnormality is a key component to assist parents in understanding and planning further management of the pregnancy. At present, ultrasound is the main imaging modality, along with Magnetic Resonance Imaging (MRI) in some circumstances of congenital abnormalities. In the same way that student's express difficulty in transforming two dimensional (2D) images into 3D in their head, patients also struggle with this issue. VR could have a beneficial role in providing a standard 3D view of congenital abnormalities, which will allow parents to understand the congenital abnormality. As this researcher's background is in Obstetrics and Gynaecology, I was also interested in the role of VR as a potential tool for patient education.

Furthermore, it is widely acknowledged in the literature that first pregnancy and second trimester ultrasound scans are the main factors of initiating the maternal-fetal attachment process (Siddiqui and Hägglöf, 2000). Maternal-fetal attachment is described as a bond that forms between the mother and the baby during the pregnancy (Güney and Uçar, 2019). This process is essential in the development of a healthy relationship between mother and baby. Prior to ultrasound, feeling fetal movements was the main component that initiated this natural phenomenon (Lerum, 1988). In addition to the benefit of VR providing visualisation of what the baby looks

like in the womb, based on the evidence above we hypothesise that it may enhance the bonding process between the mother and the baby.

With regard to the subspecialty of Fetal Medicine in Obstetrics, VR is also being used to assist in the diagnosis and management of congenital abnormalities. An initial publication by Werner (2010) detailed a work-flow process to develop 3D printed models of fetuses using a combination of 3D ultrasound and magnetic resonance imaging (MRI) which provided the basis for future studies (Werner et al., 2017). Further studies used the same work-flow process, one of which trialled virtual bronchoscopy in a fetus with congenital diaphragmatic hernia prior to a high-risk *in utero* procedure known as fetoscopic endotracheal occlusion (FETO). The fetus' trachea was visualised in 3D, which allowed virtual imaging of the fetal trachea and allowed for better technical pre-operative planning of the procedure (Tonni et al., 2018). In relation to patient education, Werner went on to publish a study demonstrating the beneficial use of VR to assist in patient education using the previously described workflow process to develop the 3D models. Parents who were given a diagnosis of a congenital abnormality in the antenatal period were given a 3D printed models of the fetal abnormality so they could physically see and feel what the fetus looked like (Werner et al., 2015). A case series was also published by Werner (2017), which looked at VR for patient education. The study concluded that 3D physical models provided the parents who had a diagnosis of Apert syndrome (a rare cause of craniosynostosis) with an increased understanding of what their baby looked like inside the womb (Werner et al., 2017). Ongoing and future research in this field is very promising. Research in this area is in its infancy today with experimental studies as described above, further research is required to assess the use of VR in this area.

The primary aim of this current Chapter is to outline the development process of 3D models of congenital abnormalities that can be put into a VR environment for patient education. The second aim is to present a pilot case study, as proof of concept for a proposed future case series on VR for patient education of congenital anomalies.

6.3 Methods

6.3.1 Study Design of "VR Baby": VR Models of Congenital Abnormalities

Institutional ethical approval was obtained from the Research Ethics Committee at the National Maternity Hospital (Reference No: EC23.2019 and EC04.2020) to carry out the study entitled: "*Development of 3D images of pregnancy for use in virtual and augmented reality*" and *"To investigate the role of virtual and augmented reality in antenatal patient education".* Pregnant women attending the National Maternity Hospital who have received a diagnosis of a congenital anomaly were invited to participate in this study. We collected antenatal fetal MRIs from 37 pregnant women attending the National Maternity Hospital for their antenatal care. We used them to develop 3D models of congenital abnormalities using a similar work-flow process as described in Chapter 3, Section 3.3.6, for the randomised control trial. In a proof-of-concept project, we conducted one case study to test the VR model for patient education.

6.3.2 Recruitment and data collection of MRI scans for VR fetal model development

Pregnant women attending for MRI scans at the National Maternity Hospital were invited to participate. All women attending the National Maternity Hospital for an MRI scan were included, except those who did not speak English and pregnant women under the age of 18. Pregnant women were given patient information leaflets in the

waiting room, prior to the MRI scan and given time to consider participating in the study. Informed written consent was obtained from the pregnant women who wished to participate in the study. The MRI scan was then anonymised and downloaded to a hard disc. Data collection included a recruitment log and consent forms (hard copies). The anonymized MRI discs were uploaded to a secure password protected UCD linked google drive.

6.3.3 "VR Baby" Educational Tool Development

VR models of congenital anomalies were developed in conjunction with the UCD Computer Science Department. Anonymised MRI DICOM data was firstly converted to stereolithography (STL) format by Axial 3D (Medical 3D printing Experts Ltd.) and then imported into Unity 3D for formatting and modification. Similarly, to the issue we had with image quality in MRI files during the development of the VRLE for the lesson on "Stages of fetal development" in Chapter 3, there was poor image quality from the MRI data files due to the slicing quality. Therefore, the computer science team modelled the 3D fetuses in "3ds max" (Autodesk Inc.), a computer graphics programme, using the MRIs and added to the model using new polygons on the surface of the original model, in a technique known as retopology. This technique may introduce change and therefore bias into the original structural defect and therefore distort the original image. Future work on the area and technique may improve the ability to transform DICOM images directly which are true to form. Our resources were limited in this capacity. The textures were modified in Photoshop and substance painter. Next, the model was placed in a VRLE and assembled in Unity3D (Unity Technologies), a game engine. The work-flow process is outlined in Figure 28 and is quite similar to that used in the RCT, as described in Chapter 3, Figure 3.3. Throughout the development process, expert guidance was provided by an Obstetrics and

Gynaecology professional (FMcA) to ensure medically correct reconstruction of the congenital abnormalities in the VR models. Figure 28 below details the workflow process for the 3D model development.

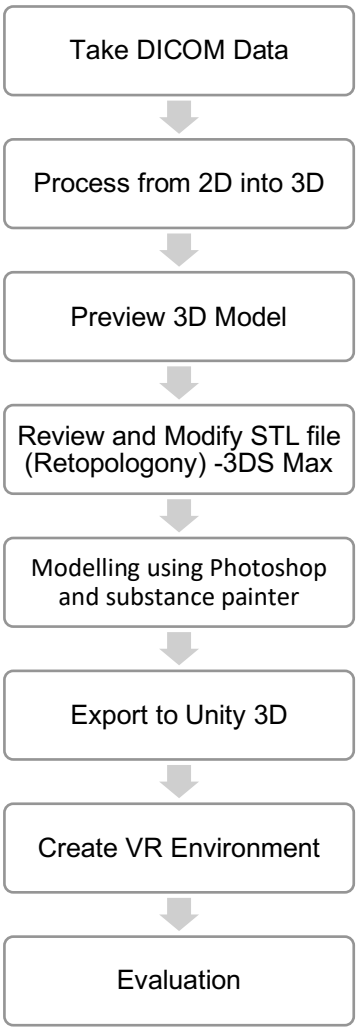


Figure 28 Work-flow process to develop VR Models of congenital anomalies

Three VR models were developed in total as a pilot project and included the following anomalies: a congenital diaphragmatic hernia, spina bifida, and ventriculomegaly. For comparison during the case study, I placed the fetus with the abnormality beside a fetus that had normal anatomy. Illustrated in Figure 29, congenital diaphragmatic hernia is a condition of the thorax that arises from abnormal development of the

diaphragm. It occurs during fetal development, when there is a hole in the diaphragm, which is the muscle separating the chest from the abdomen. A gap may form in the diaphragm during the development of the fetus in the womb and organs such as the bowel, stomach, or even liver can move into the chest cavity through the gap in the diaphragm. It occurs in approximately 1 in 3000 births, accounting for 8% of all birth defects and is associated with a high mortality rate of 1-2% (Wynn et al.).

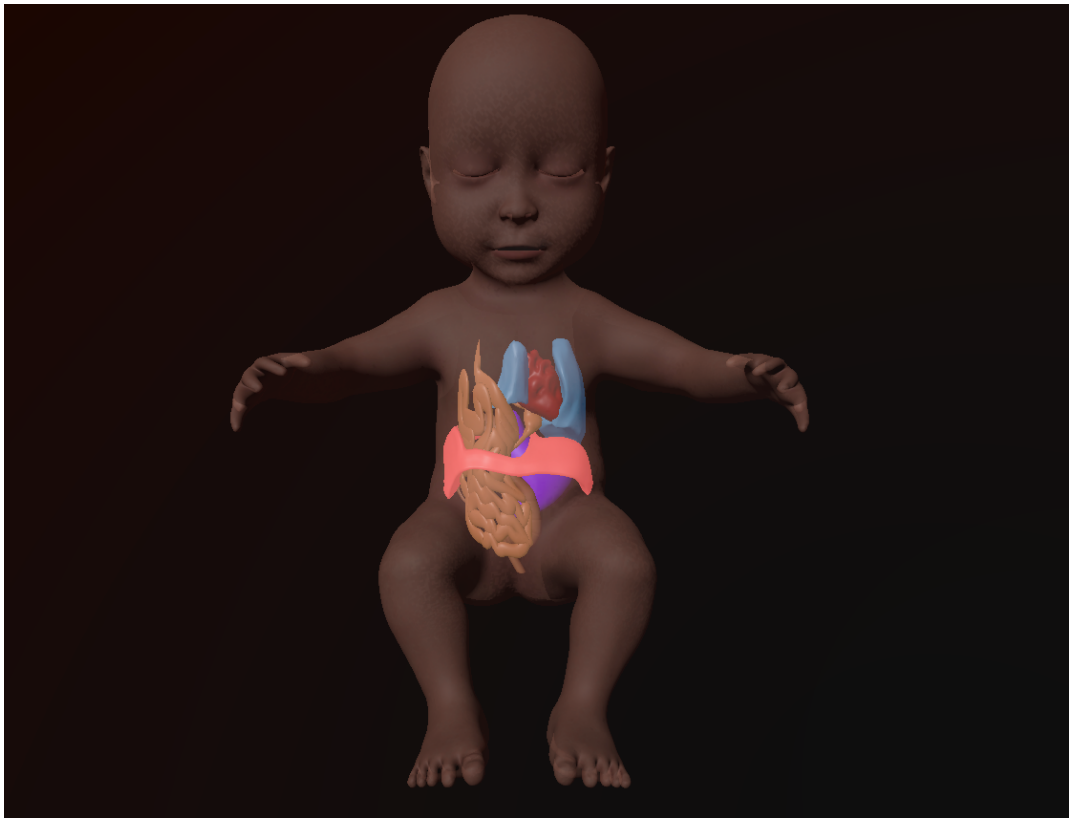


Figure 29 VR model of a right-sided Congenital Diaphragmatic Hernia

Spina bifida is a neural tube condition that means the babies spine and spinal cord do no develop properly inside the womb, leading to a gap in the spine (Figure 30 and 31). It occurs in approximately 1 in 1000 births and can range in location, size, and severity. Most cases require surgical repair, which can be carried out *in utero* or after birth.

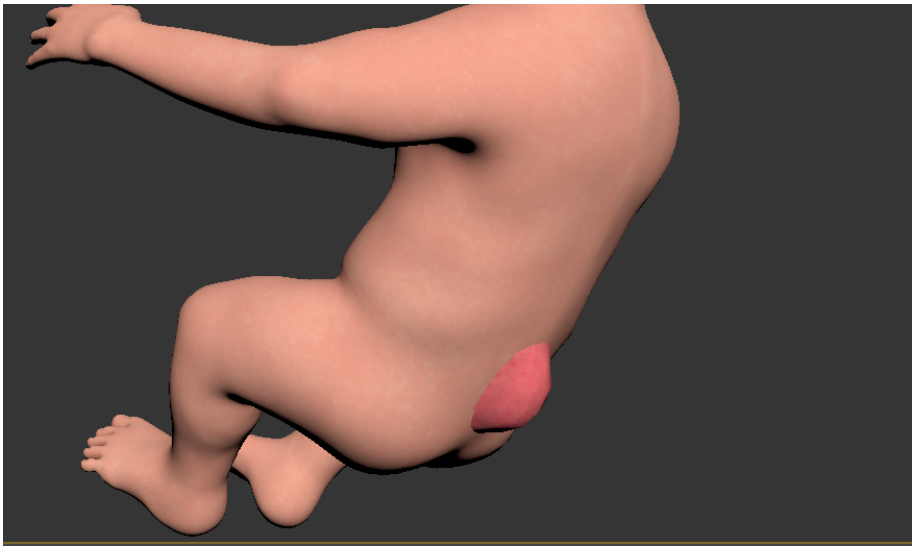


Figure 30 VR Model showing fetus with a lumbosacral spina bifida

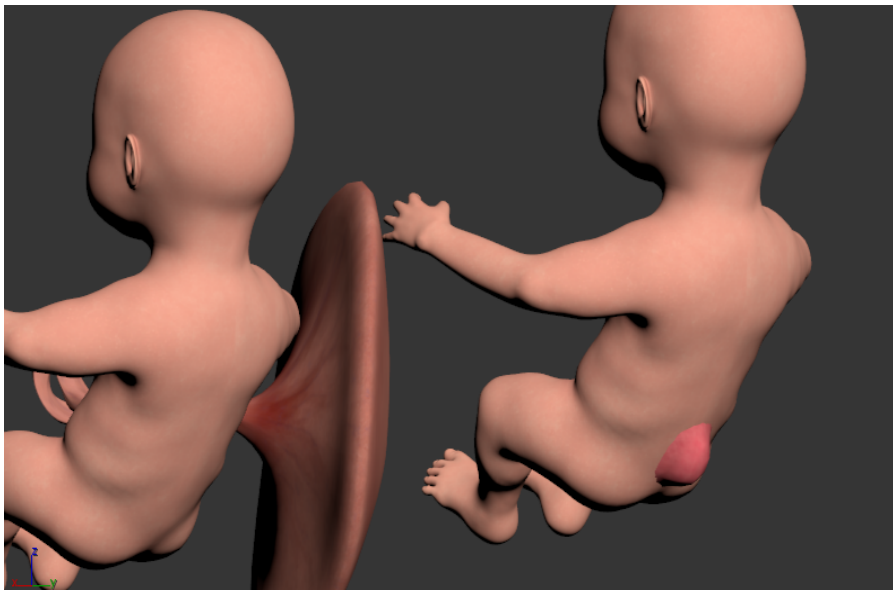


Figure 31 VR Model of Fetus with Spina Bifida on the right and a fetus with no spina bifida on the left for comparison

Ventriculomegaly is a condition in the brain which also occurs during development in the womb, where there is an increased amount of cerebro-spinal fluid (CSF) in the ventricles of the brain (Figure 32 and 33). It occurs in approximately 1 in 100 births and ranges in severity from benign to a link with another condition known as

Hydrocephalus, which is an enlargement of the ventricles due to an increased pressure in the CSF. We chose the above three cases, as they were part of the cases collected in the data collection and the MRI images in these cases had the least amount of fetal movement.

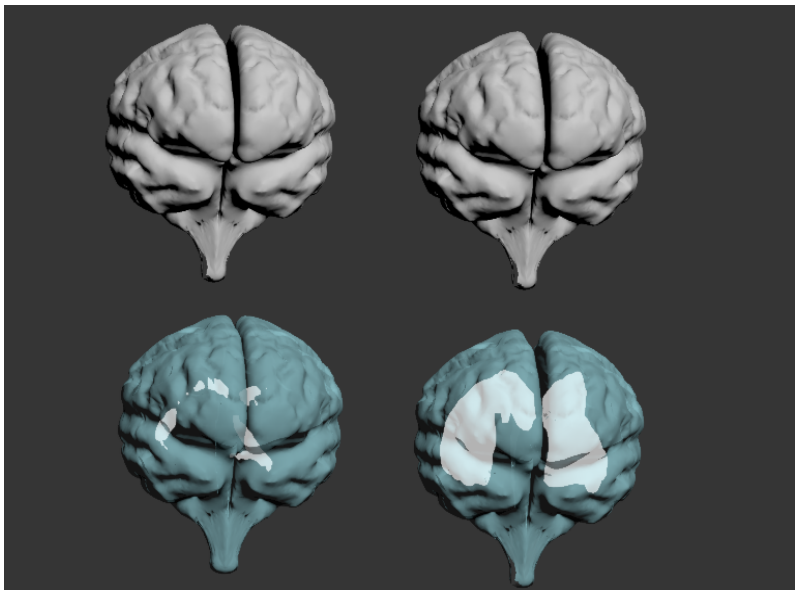


Figure 32 VR Model of Ventriculomegaly. The outside of the brain is shown on the top in grey and the bottom right brain shows ventriculomegaly and the brain on the left shows normally sized ventricles

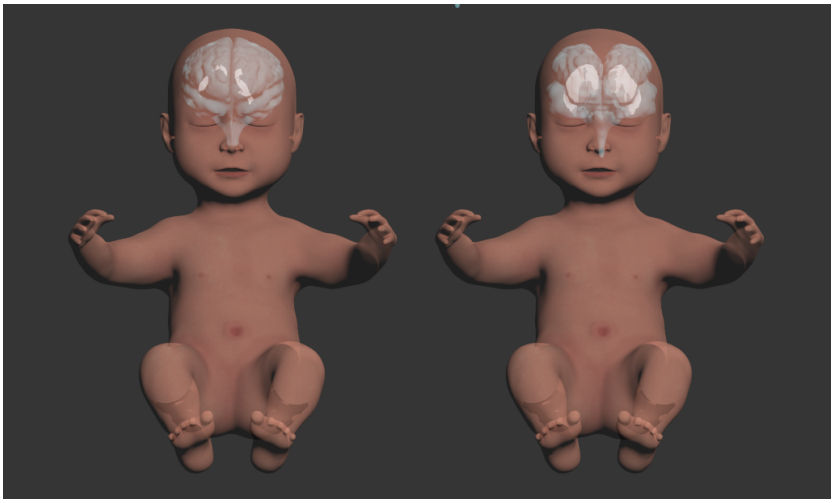


Figure 33 VR model of ventriculomegaly seen on the right side and a normal VR model of the brain and ventricles on the left side of the picture

The MRI DICOM data also gave us the data to build a VR model of fetal circulation during the development of the 3D models. In conjunction with the computer science team and expert guidance from Obstetrics and Gynaecology professionals (FMcA and GR), we developed a 3D model of fetal circulation for a VRLE. This model could be used in the future for student education at our research centre. An image of the fetal circulation is seen below in Figure 34 and 35.

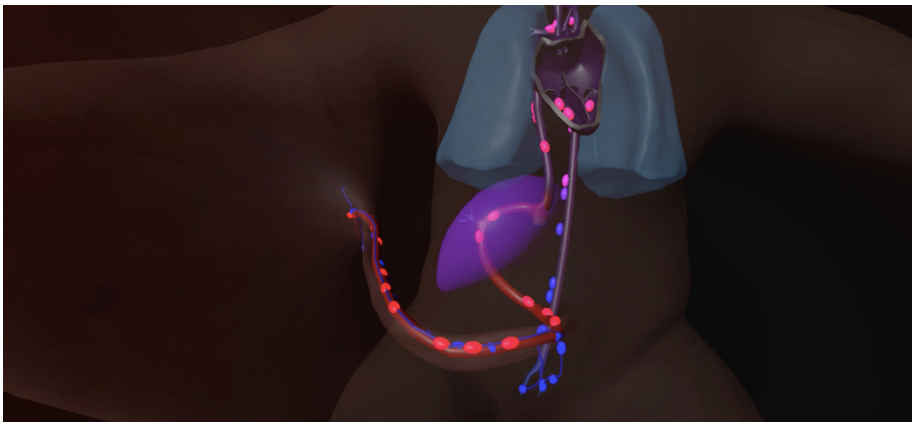


Figure 34 VR model of fetal circulation

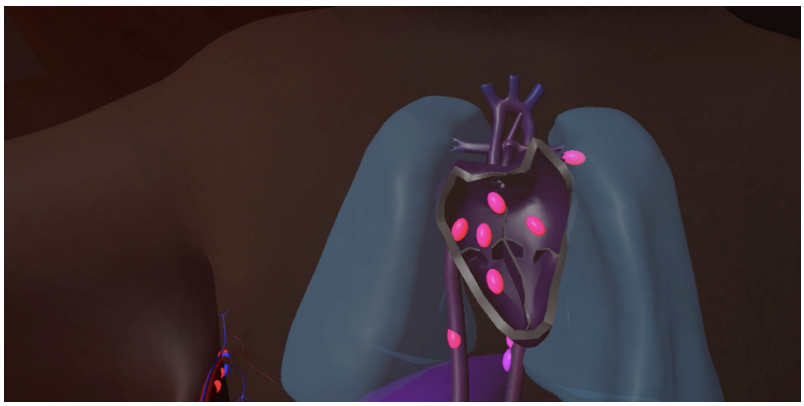


Figure 35 A close up image of the fetal heart

6.4 Case study of “VR Baby”

Following the development of the 3D models, they were placed in a VRLE using the Oculus Quest headset. The next part of this research project included a proof-of-concept test case study to assess whether the VRLE could be used in a patient case series in the future to help enhance understanding of some congenital abnormalities in the womb during pregnancy for parents. The next section details the case study of a pregnant women in the antenatal period whose baby has a congenital diaphragmatic hernia. She used the Oculus headset to undertake the VRLE of a congenital diaphragmatic hernia and completed a questionnaire on her experience.

This is a case of a 28-year-old female, who was 32-weeks’ gestation in her first pregnancy. She is fit and healthy, with no past medical or surgical history of note and no known drug allergies. She was referred from a peripheral hospital to the Fetal Medicine team at the National Maternity Hospital with a suspected diagnosis of congenital diaphragmatic hernia at 26-weeks’ gestation. A diagnosis of a left-sided congenital diaphragmatic hernia was confirmed. She attended the Fetal Medicine team for regular review, and she also underwent a fetal MRI which confirmed the diagnosis and showed that the left lobe of the liver and spleen were displaced upwards through the defect in the diaphragm in the chest cavity. At 32-weeks’ gestation, she attended for a follow-up appointment with the Fetal Medicine Team. At this visit, she was invited to take part in the study and was given an information leaflet, following which she provided informed written consent. She was provided with instructions on how to put the Oculus Quest headset on and how to use the hand controllers to navigate inside the VR environment. The researcher was present for the entire time to guide the participant through the VR educational tool.

For the purpose of the pilot case, I asked a series of Likert-style questions based on the Maternal-Fetal Attachment Scale to gauge the feasibility of using the VR tool. She completed a simple questionnaire and provided feedback after the VR experience.

The patient's questionnaire responses are detailed below in Table 31. Of note, she was 32-weeks from diagnosis in the third trimester of her pregnancy and had felt that it did not add any educational value to her knowledge of Congenital Diaphragmatic Hernia (CDH) at this time. However, she said that, if she had used this at the time around the diagnosis, it would have helped her to understand the diagnosis better as she went on "google" to look at images of CDH.

Table 31 Pilot case study of "VR Baby" Questionnaire response

Questionnaire	Responses
How does it make you feel visualising the 3D baby with CDH?	Somewhat positive
Over the past few weeks have you had the desire to read about or get information about the development of your baby?	Agree
Does this learning experience help you to understand your baby's condition better?	Agree
Will this VR experience help you to bond better with your baby?	Agree
Could you imagine what they baby's anatomy looks like after completing the VR learning experience?	Agree
Do you think tools like VR headsets could help parents that have had a prenatal diagnosis of a congenital abnormality?	Strongly Agree

6.6 Discussion

I successfully developed “VR Baby”, educational VR models of congenital abnormalities for patient education using MRI images and post-processing software. The VR models are the first 3D objects of congenital abnormalities that this author is aware of at both local and national level. The advancement of technology is providing innovative methods for patient education. The case study performed highlighted that the VR model was not helpful at such a late gestation and perhaps would have been more beneficial at the time of diagnosis. This project is very novel and has the potential to enhance patient education. However, further research is required to establish an evidence-base for the use of VR in these circumstances.

From the published literature and the studies presented in this thesis, we know that VR provides an environment for visualisation of 3D objects and this can help in circumstances where translation from 2D objects to 3D objects is required . This could help patients understand what their baby looks like inside the womb. It may also assist as a visual learning tool to explain a complex diagnosis like congenital diaphragmatic hernia. With regard to maternal-fetal attachment, visualising the image of the fetus in 3D may enhance the bonding process. In a study by Gudex (2006), they found that pregnant women request prenatal ultrasound screening for a variety of reasons including seeing the baby and wanting an ultrasound picture of the baby. In addition, the vast majority sought reassurance with regard to the presence of anomalies (Gudex et al., 2006). Interestingly, a study carried out by Sedgmen (2006) demonstrated that 3D US did not offer any enhanced benefits, compared to 2D US, in relation to the Maternal-fetal attachment profile (Sedgmen et al., 2006). With the advancement of technology and high-quality VR applications available that promote engagement and

active participation, it would be interesting to carry out further research, as proposed, to assess if it influences the bonding process between the mother and the baby.

6.6.1 Strengths and limitations

A strength of “VR Baby” is that it is a very novel learning tool that has the potential to provide a visual aid in Fetal Medicine, where parents may find it difficult to grasp structural defects in congenital abnormalities. A key concern in the development of the images was the quality of the MRI images, which is due to a variety of factors including fetal movements throughout the scan and the MRI settings on the “slicing” function. The quality of the MRIs obtained for this study did require post-processing and modifications to the surface by process of retopology to prevent deformed 3D objects. This led to potential distortion from the original image, which could be misleading for the patient, presenting a more standardised model rather than their own babies’ images. Retopology is a process, where the surface area of a 3D file, known as the mesh, is simplified to make it cleaner and allow for modifications (Blender). This allowed us to reconstruct the congenital abnormalities with validation from experts in the field. As noted in our previous studies, a limitation of VR is the cybersickness, therefore it may be advisable to have patients sit during the learning experience to minimise any potential risk or harm to the patient and fetus. Future research could involve a case series of patients diagnosed with congenital abnormalities using the VR model to assist in patient education.

6.7 Conclusion

In conclusion, I successfully developed VR Babies, three educational VR models of congenital abnormalities for patient education. A pilot case study on a patient with a diagnosis of congenital diaphragmatic hernia was presented, where a 3D model of

CDH was used to educate the patient. Key information on the timing of using the model was gained from the case study. Research in this area is in its infancy with a need for future research on this topic. The VR models and pilot case study can be used to inform future research projects on the use of VR models for patient education, specifically in the diagnosis of congenital abnormalities.

Chapter 7 Summary, Conclusions and Future Research

7.1 Summary

The aim of this thesis was to explore the role of a VRLE in healthcare student education, with regard to knowledge acquisition and the learning experience via standardised assessment tools, coupled with investigating VR feasibility in relation to side effect profile and cost. The findings and results of this thesis contribute to the growing body of evidence on VR learning tools.

This thesis involved conducting a systematic review of immersive technologies across three fields of healthcare university education: medical, nursing and midwifery education. Based on the findings of this study, I conducted a randomised controlled trial and mixed methods study, evaluating knowledge via MCQs and the learning experience via standardised validated instruments. In conjunction with the Computer Science team, I developed our own bespoke VR educational tool, a virtual reality learning environment (VRLE), named “VR Baby”. Three-dimensional lessons for “VR Baby”, pertaining to the Obstetric and Midwifery curriculum were placed into the VRLE, “VR Baby”, which I trialled in a medical and midwifery student population. I explored students’ knowledge acquisition, learning experience, and side effect profile, along with a cost analysis of such an innovative educational learning tool. Following this I developed 3D models of congenital abnormalities for patient education in the field of fetal medicine. I presented a case study that evaluates the patient perspective of the VR learning tool. My work contributes to the growing body of evidence on the use of VR in healthcare education.

Educational theory was a key component in the development and implementation of “VR Baby”, our VR learning tool. The conceptual framework implemented, guided the development of the lesson plan and learning objectives supported by principles of

constructivism and experiential learning theory. The VRID model facilitated the technical aspect of developing the VRLE in a structured and informed manner. Principles of constructivism, and experiential learning theory were also applied to the VRID model in conjunction with Mayer's cognitive theory of multimedia learning. The resulting VR learning tool "VR Baby" creates a learning experience for the learner that facilitates building on prior knowledge and combining new knowledge and ideas, in a self-regulated active learning process. My research also demonstrates that VRLEs such as "VR Baby" can be utilised as a self-directed learning tool, which have the potential to be used by students anywhere or at any time. This research was conducted during the global pandemic COVID-19, which also highlighted the value of VR in circumstances where students have to learn from home or have reduced access to clinical settings, as VR devices are an alternative device that can be used for learning in home settings. It also demonstrates the benefits of a tool for long-distance learning.

In particular, our research highlights the use of VRLEs in Obstetrics and gynaecology and midwifery education, where 3D visualisation resulted in equal levels of knowledge acquisition and an enjoyable learning experience despite a high incidence of side effects. I conducted an RCT that found no change in knowledge scores between groups following the intervention. Similarly in the mixed methods study, knowledge scores increased after the VRLE, although not statistically significant. Validated instruments (The Student Satisfaction in Learning and Self-Confidence Scale) evaluating the learning experience allowed us to standardise the assessment of the VRLE. Secondary outcomes revealed participants high levels of satisfaction and self-confidence in learning with "VR Baby" reflecting a positive attitude towards the VRLE. Despite the positive attitude towards "VR Baby", our study findings demonstrate the

high incidence of side effects associated with VR learning tools. The qualitative analysis provides a valuable insight into participants views and opinions on the use of VR, including the enjoyment value and side effect profile.

I also carried out a cost analysis in line with national and international guidelines to add to the feasibility of “VR Baby”, a VRLE learning tool. Results showed that it is a more costly learning tool. This is valuable information that can inform relevant stakeholders in education and future research in the area. My research adds to the current literature and informs future research on VR learning tools, with regard to the development process, knowledge outcomes, learning experience, side-effects and cost of a VRLE in healthcare university education.

7.2 Main findings

In Chapter 1, I introduced the topic of educational technologies and reviewed the literature, detailing the evolution of immersive educational technologies over the last century from pen and paper to novel mixed reality simulation tools. I discussed the main learning theories that are thought to inform educational VR technology and reviewed how learning theories are utilised in the pedagogical development of effective immersive educational tools and discussed the factors that have influenced the use of immersive technologies in healthcare education, including changes in training standards, the changing nature of health care delivery systems, changes in the curriculum, coupled with a new generation of learners, as well as the advancement of technology and economic factors.

Following this I linked how the use of conceptual frameworks helps to further guide the educator in developing and structuring a lesson plan with pre-specified learning objectives. A conceptual framework informed by experiential learning and constructivism supports the use of VR in medical education.

Following this I discussed the use of VRID, an instructional design model for VR technology and the steps of the process and proposed the conceptual framework and VRID model to develop a VRLE. Finally, I presented the potential benefits and challenges that face the implementation of immersive technologies in healthcare education.

In Chapter 2, a systematic review was conducted to evaluate the learning outcomes of immersive educational tools compared to traditional educational tools in medical, midwifery, and nursing student education. RCTs that evaluated learning outcomes of an immersive educational tool, compared to a traditional educational tool within a

population of medical, midwifery, and nursing student education, were analysed. Strict inclusion criteria adapted in this review meant that comparisons could be drawn clearly, and evidence-based conclusions could be deduced for the population under review. The systematic review concluded that immersive technologies are an effective educational tool in medical and nursing education. When compared to traditional educational tools immersive educational tools i.e. VR, AR, or MR demonstrate equal or improved knowledge acquisition and an enhanced learning experience.

In Chapter 3, I introduced “VR Baby”, the VRLE developed and used in the RCT, the mixed methods study (Chapter 4) and the patient education pilot case study (Chapter 6). I developed the bespoke designed VRLE in conjunction with the UCD Computer Science team and created two lessons in 3D on topics relating to Obstetrics and Midwifery education, and 3D models of congenital abnormalities for patient education, that were all placed into the VRLE which I entitled “VR Baby”. I applied a conceptual framework informed by experiential learning and constructivism to develop a lesson plan and learning objectives on topics pertaining to the Obstetric and Midwifery curriculum. The content and lesson design was developed using the VRID model, as proposed by Chen (2010), an instructional framework which outlined the stepwise design process and roles within the team to develop “VR Baby”, which are described in chapter 3. I collaborated with the UCD Computer Science team in the development of these educational tools, which enabled me to gain an understanding of the development process from start to finish.

In Chapter 3, I assessed a VRLE compared to a traditional didactic tutorial amongst a population of medical students in a prospective unblinded RCT. As detailed above, I developed and built a 3D lesson on a topic pertaining to the Obstetrics and

Gynaecology curriculum, namely “Stages of Fetal Development” for input into the VRLE, “VR Baby”.

I evaluated the learning objectives including knowledge differences between groups via an MCQ test as the primary outcome. In relation to secondary outcomes, the student learning experience, I adapted a previously validated instrument used for simulation studies; the “Student Satisfaction and Self-Confidence in Learning Scale” (SCLS) and the “Simulation Design Scale” (SDS; renamed VRDS for the purpose of this study). I proposed these instruments as a standardised approach to evaluating the learning experience of immersive technology.

The VRLE demonstrated equal levels of knowledge acquisition, compared to a traditional didactic tutorial. Interestingly, there was no statistically significant increase in knowledge scores between the two groups. In the discussion I review the factors that may have influenced this result which were possibly attributed to a difference in baseline characteristics, high baseline knowledge in both groups and a heterogenous population under evaluation. Furthermore, on reflection the primary outcome did not assess the strengths of VR learning tools i.e enhanced understanding and spatial awareness of 3D structures in anatomy and embryology education.

With regard to the learning experience, the intervention group reported high mean scores, illustrating a high level of satisfaction and self-confidence with the learning experience. “VR Baby” was rated highly on the VRDS scale, strengthening the support for using the VRLE and contributing to content and face validity of the learning tool. High mean scores from the VRDS suggest user satisfaction with the 5 constructs of the scale: objectives; support; feedback, problem-solving and fidelity. One of the most interesting findings was the side effect profile of “VR Baby”. The most commonly

reported side effects were disorientation dizziness, impaired balance, and symptoms similar to motion sickness, with 50% of the participants experiencing dizziness or disorientation.

The findings from this study contribute to the expanding evidence-base of research on VRLEs, demonstrating that VRLEs can be used to help students learn and provide a favourable learning experience. Cybersickness was reported in nearly half of the study participants, which may reflect a challenge for its implementation into the curriculum. The rates of cybersickness are poorly reported in the literature, therefore our study is an important contribution to the literature in this regard (Servotte et al., 2020a). It is also worth noting that, with the fast-paced world of technology, VR headsets are being modified constantly and upgraded, with the expectation that this will improve cybersickness in the future.

In Chapter 4, a mixed methods study exploring the use of “VR Baby” was conducted amongst a population of midwifery students. Again, I developed a 3D lesson for the VRLE (“VR Baby”) pertaining to a complex topic in midwifery education, fetal lie, position, and presentation in the third trimester of pregnancy. Similarly to Chapter 3, I employed a conceptual framework based on experiential learning and constructivism to develop a lesson plan and learning objectives on the topic of fetal lie, position and presentation. Similar to the RCT, the results from this study showed no significant changes in knowledge in the midwifery student population; however, the learning experience was still rated highly. Results from qualitative analysis illustrated a positive attitude towards the VRLE.

Similarly to the RCT in Chapter 3, cybersickness was also viewed as a limiting factor in this cohort and found to cause similar rates of cybersickness to medical students,

which further validate the findings in the RCT. As mentioned previously, there is a lack of assessment or reporting on the side effects of VR learning tools in the literature, so these findings are an important contribution to the current literature. Within Midwifery education this is a novel use of VR learning tools, with no similar published reports in the literature. This contributes to the growing body of research with regard to the use of VRLEs within this discipline.

In Chapter 5, I carried out a cost analysis to assess the feasibility of VR tools from the perspective of the university. International guidelines on conducting cost analysis in medical education informed a thorough cost analysis of our VRLE. The VRLE was costed under two settings, one during COVID-19 and the second outside of COVID-19. Study findings illustrated the increased demand for VR during the global pandemic COVID-19, highlighting the increased worldwide availability of these immersive tools and their potential as a self-directed learning tool, that students can have at home or for the purposes of long-distance learning. Findings of the cost analysis revealed that the VRLE was more costly to develop compared to the cost of traditional learning. Nevertheless, my study acts as a future guide to inform relevant stakeholders within the field of medical education.

Chapter 6 explored the use of VR for patient education. In conjunction with the Computer Science team, I developed three VR models of congenital abnormalities namely spina bifida, ventriculomegaly and congenital diaphragmatic hernia. I presented a pilot case study as a proof of concept to demonstrate how VR learning tools can help patients to visualise what their baby looks like inside the womb, specifically when receiving a diagnosis and counselling of a pregnancy with a congenital abnormality. Based on the same concepts mentioned above, it could

potentially act as a visual aid to explain complex diagnoses relating to structural congenital anomalies.

VR educational tools are useful learning tools, and our study findings highlight that they can improve knowledge similar to traditional methods and enhance the learning experience. However there is a high incidence of side effects associated with the VR learning tool that may be a limiting factor in its implementation and acceptance within medical education. This research demonstrates positive feedback and appreciation for the potential benefit of VR from the perspective of the student. However I have also identified challenges that face the implementation of VR educational tools in medical education. Feedback from qualitative analysis suggests that this innovative technology is a useful tool to visualise fetal development and the spatial relationship of the fetus to the pelvis, and an enjoyable learning experience, with disadvantages of the technology including cost and cybersickness, which may challenge its implementation into the curriculum. However it should be remembered that educational technology is a support tool for educators and learners and is not a replacement for the traditional delivery methods of the core curriculum or research.

7.3 Comparison to the Literature and Clinical Implications of the Results

7.3.1 Learning Outcomes of Immersive Technologies in Healthcare Student Education: A Systematic Review of the Literature

The main findings of the systematic review highlight that immersive technology when compared with traditional learning modalities, results in equal knowledge gain, improved clinical skills and an enhanced learning experience. RCTs were selected for this current review that compared the learning outcomes of an immersive educational tool with a traditional educational tool. The primary outcome was knowledge in 97% of studies under review and I learned that there is a heterogeneity of tools, both validated and unvalidated, to assess the learner experience.

No studies formerly assessed costs or patient outcomes according to the MERSQI study tool. Our study is the first to evaluate immersive educational tools, including VR, AR, and MR in the healthcare student population, which included pre-clinical medical, nursing and midwifery students collectively. The published literature, to date, reflects similar findings, concentrating on one specific immersive technology, population cohort or specific clinical area or subject (Tang et al., 2020, Zhao et al., 2020). In addition, learning objectives are often inconclusive and difficult to report. The findings from this study are used to inform the study design and evaluation tools of the RCT and Mixed methods study presented in Chapter 3 and 4.

Lastly, a key finding in the systematic review was the lack of a standardised instrument to evaluate the learning experience with regard to student satisfaction, self-confidence, engagement and motivation. This informed the development of the evaluation and assessment components for both the RCT and mixed methods study. A validated outcome instrument that is used to evaluate the learning experience of all

VR learning tools would allow researchers to critically appraise study findings in a systematic manner. This could potentially enhance the quality of evidence of the learning experience associated with VR learning tools.

Our study findings are reflected in the literature. The Digital Health Collaboration carried out an extensive analysis evaluating the effectiveness of VR in healthcare professions education, concluding that VR improved post-intervention knowledge levels and skills (Kyaw et al., 2019d). Only VR and both pre- and post-clinical healthcare professionals were included, concluding that further research is required on learning outcomes such as satisfaction, engagement and motivation, costing of immersive technology and the side-effects. Similarly, a recent review by Zhao (2020) assessing the effectiveness of virtual reality-based technology on anatomy teaching, concluded that VR is an efficient way to improve learners' levels of anatomy knowledge. It also acknowledged that there is a lack of reporting on other learning objectives such as satisfaction, engagement, and motivation, in conjunction with cost analyses and reporting of adverse events (Zhao et al., 2020).

This study contributes to the current research on the learning outcomes associated with VR learning tools, which is a very exciting and important topic within the field of medical education.

7.3.2 "VR Baby" Studies

Virtual reality (VR) is becoming an increasingly popular educational technology that offers an immersive experience to promote discovery and exploration of personal knowledge, and an opportunity to learn by doing, develop creativity, and increase understanding of invisible concepts (Kyaw et al., 2019d). From the research carried out in this thesis, it is clear that a VR learning tool that is developed using a

model with a clearly defined conceptual framework and learning objectives is an effective method for learning. However it is important to understand how educational theory is applied to conceptual frameworks and instructional design in order to develop an effective educational VR learning tool.

VR technology is thought to be supported by principles of constructivism and experiential learning theory. Our experimental studies detailed in Chapter 3 and 4, demonstrate how these learning theories are applied to the development of a VRLE. Understanding how educational theory guides and supports conceptual frameworks allows educators to align the strengths of the VR learning tool with the learning objectives and the assessment. Various studies have highlighted the lack of educational theory and instructional design models to support the development of VR learning tools in the literature. Best practice guidelines are calling for the reporting of clearly defined conceptual frameworks and instructional design models when developing VR learning tools (Issenberg et al., 2005).

With that in mind, I designed a VRLE, “VR Baby” in conjunction with the UCD Computer Science team in a multidisciplinary collaboration. The use of the VRID model as proposed by Chen (2010) is an important strength of our research and further research in the field should endeavour to use standard instructional design models when developing VR educational technology. A recent study published by Birbara (2021) proposes an alternative instructional design model to develop VR learning tools for anatomy education (Birbara and Pather, 2021). With an increasing amount of research in the area of VR, more instructional design models are being proposed and implemented in the development of VR learning tools. Park (2022) also discusses the importance of instructional design in the development of VR learning tools. Results

demonstrated that the use of instructional design to develop VR learning tools affected educational satisfaction. The Healthcare Simulation Standards of Best practice consider instructional design of simulation including VR simulation an important factor for the achievement of learning objectives (Committee, 2016).

In relation to VRLEs within Obstetrics and Gynaecology education, there have been a few studies published that have developed VRLEs on embryology related topics, though; no evaluation of the tool was carried out in these studies (Popovici et al., 2017a). As discussed previously a VRLE offers a promising opportunity to enhance understanding of 2D structures and physiological processes that can't be visualised. This is relevant to subjects like anatomy and embryology where students are required to translate two-dimensional (2D) images into 3D images. Werner (2019) detailed the development process using three-dimensional ultrasound (3D-US) and magnetic resonance imaging (MRI) scans to develop 3D objects of the fetus, which show it is possible to develop models from obstetric 3D-US and fetal MRI (Werner et al., 2017). However this study used the VR tool for patient education only and was not tested in a medical student population. Our team did not have the resources and finances available to replicate the same development process of our 3D models.

The development of "VR Baby", our VRLE, gave rise to two lessons on key topics pertaining to Obstetrics and Midwifery education, in addition to 3D models on congenital abnormalities. This gave me an insight into the development process and the necessary requirements to create and build such an immersive learning tool. From the research carried out in Chapter 1, I was able to apply principles of constructivism, experiential learning theory and Mayer's cognitive theory of multimedia learning to the development of VR Baby and associated learning objectives.

7.3.3 "VR Baby", A virtual reality learning environment to assess the learning outcomes of medical students: A randomised controlled trial

I conducted an RCT to compare the educational effectiveness of "VR Baby" with traditional teaching on the subject of embryology in a medical student population, evaluating factual knowledge and participant learning experience.

I adapted a previously validated outcome instrument, SCLS scale and proposed the instrument as a standard tool to evaluate the learning experience of VR learning tools, coupled with the VRDS scale to assess the validity of the tool and record the side effect profile.

Our RCT found no difference in knowledge scores post-intervention between groups. This supports findings from our systematic review. In contrast, a systematic review carried out by the Digital health collaboration found evidence to suggest that VR improves knowledge (Kyaw et al., 2019d). In a meta-analysis of 36 studies, 21 assessed knowledge acquisition as the primary outcome with a pre-test/post-test design (Yammine and Violato, 2015). This author notes that there is an increasing amount of evidence to support equal or improved levels of knowledge with VR learning tools which is an important finding to establish evidence-based research on VR learning tools. From my research VR learning tools are thought to increase knowledge, enhance spatial awareness and facilitate a fun and engaging way to learn. Assessing the educational effectiveness of VR learning tools encompasses a variety of elements. The majority of studies in the literature and our study focused on knowledge acquisition as the primary outcome. However, one of the main strengths of VR learning tools is the ability to enhance understanding of 3D concepts in anatomy and embryology education and not knowledge acquisition. Perhaps a shift in focus is

required from investigating knowledge as the primary outcome to evaluating the ability of VR to enhance understanding and spatial awareness. On reflection of our results the primary outcome was not matched to assess the strength of VR Baby i.e spatial awareness. If I were to repeat this study, I would include an assessment of spatial awareness in addition to factual recall.

With regard to secondary outcomes participants had a positive learning experience, reporting high levels of satisfaction and self-confidence with the VR learning tool. Our thematic analysis also saw participants favouring the use of VR learning tools, with participants acknowledging the potential of VR to enhance understanding of 3D objects in anatomy and embryology education. Evaluating the learner experience is an important task for educators, in a learner centred approach the educator can determine how learners are progressing in their education and allows the learner to give feedback on educational activities (Taylor and Hamdy, 2013). With this information educators can structure learning in a more personalised, relevant and engaging way. Therefore this is an important finding in our study coupled with the fact that we used validated scales to assess the learner experience.

Lastly, a key finding in our study is the high incidence of side effects reported by participants. As mentioned previously cybersickness is a common side effect of VR technology. In our study almost half of the participants using “VR Baby” experienced disorientation. There is a paucity of evidence or reporting in the literature on the side effect profile of VR learning tools. A systematic review and meta-analysis by Kyaw (2019) found that out of the 31 studies included for evaluation, no study evaluated side effects or adverse effects of VR technology. With the advancement of technology, improvements and updates in hardware and software components are constantly

being made which may see a reduction in the side effect profile. Interestingly, in our study students still gained knowledge and reported an overall positive learning experience despite experiencing side effects.

7.3.4 "VR Baby", A Virtual Reality Learning Environment for Midwifery Students: A Mixed Methods Study

To my knowledge, this is the first study that has been carried out with midwifery students on VRLEs as a visual aid to enhance understanding of complex topics such as the fetal-pelvic relationship. Most studies in nursing and midwifery education concentrate on VR simulation and the benefits of VR for the development of basic clinical skills; for example, taking a patient history or teaching nursing students how to recognise clinical signs of deterioration (Padilha et al., 2019c, Hauze et al., 2019).

The study findings in comparison to the literature of this study are similar to the RCT presented in Chapter 3 including the use of validated outcome measures, the reporting of conceptual framework and instructional design model for VR Baby in conjunction with the lesson plan and learning objectives.

Our study is novel and demonstrates the use of VRLEs in Midwifery education. Although the findings demonstrated no significant changes in knowledge, our qualitative analysis highlighted the acceptability and enhanced learning experience, despite approximately half of participants experiencing cybersickness. Our study contributes to the growing amount of research on VRLEs in the field of Midwifery education.

7.3.5 A Cost Analysis of a Virtual Reality Learning Environment to Teach Medical Students about Fetal Development for Obstetrics and Gynaecology Education

Our cost analysis found that the VRLE is more costly to implement compared to the didactic tutorial. There are very few publications in the literature that have carried out a complete formal cost analysis. I adhered to national (Health Information and Quality Authority - HIQA) and international (Association for medical education in Europe - AMEE) guidelines to conduct and report the findings of this study.

The implications of this study directly relate to the cost of the VRLE, as it is more costly than the traditional tutorial. Technology can be an expensive commodity and research is required to support evidence for its use. Technology advancements mean that there is increased availability and reduced costs of VR technology however everybody may not be able to afford it (Car et al., 2019a). This may provide the framework for future research in assessing the costs of a VR educational tools, which will inform relevant stakeholders.

7.3.6 "VR Baby" Development of VR Congenital Abnormalities for Patient Education

I successfully developed bespoke 3D models of congenital abnormalities; spina bifida, ventriculomegaly and congenital diaphragmatic hernia in conjunction with the UCD Computer Science Department and placed them in a VRLE for patient education. The value of this research lies in the potential use of VR technology for patient education. As outlined in the proof-of-concept case, the patient clearly stated that the virtual tool would have been much more useful at the time of diagnosis as she spent a lot of time on google trying to understand the congenital anomaly her baby was diagnosed with. A similar study that developed 3D models of structural congenital abnormalities to aid

patient education reports that the user perceived increased understanding of the congenital anomaly diagnosed (Werner et al., 2017). The next step in this study would be to carry out a patient case series assessing the effectiveness of VR technology to aid diagnosis and understanding of complex structural fetal anomalies. Future use of this visual tool could be beneficial in the clinical setting of fetal medicine at the time of diagnosis of structural congenital abnormalities.

7.4 Strengths and limitations

There are numerous strengths associated with the studies carried out during this research project. This author acknowledge that there are also limitations addressed below.

The main strength of the systematic review is that there are no other publications that surmise the learning outcomes associated with immersive technologies across three healthcare disciplines at university level education.

The study design of the systematic review is also a strength, which lent to the rigor of the study as opposed to a literature review. I implemented a strict search strategy and inclusion criteria, resulting in only RCTs being included in the systematic review. Additionally, using the Medical Education Research Study Quality Instrument (MERSQI) allowed me to evaluate the study design and quality of the RCTs included in the systematic review. This allowed me to draw clear comparisons and conclusions, which helped to inform the study design of the RCT with medical students and the mixed methods study with midwifery students.

Another strength of the thesis is that I created “VR Baby”, a VRLE, and made two 3D lessons and 3D models of congenital abnormalities that were all placed into the VRLE.

This process enabled me to gain an understanding of the development process from start to finish. In addition, this helped me to develop skills in collaborating with other research schools. Based on the comprehensive literature review in Chapter 1, the development of the VRLE was informed by learning theories in a conceptual framework that then guided the VRID process to build “VR Baby”.

Moving onto the RCT, the VR learning tool was developed in a standardised format supported by learning theories to guide the conceptual framework and instructional design process. The framework outlined in Chapter 3 to develop the lesson plan, learning objectives and assessment is a strength of the RCT. A conceptual framework coupled with Kerns 6-step approach to curriculum development helped to guide the development of a lesson plan and learning objectives that were mapped to the MCQ assessment. Another point to note is that the pre-defined sample size was achieved, with a high rate of follow up.

Based on the findings from the systematic review, the heterogeneity of instruments used to evaluate the learning experience led me to propose and implement an adapted version of the SCLS and VRDS scales as a standard tool for the evaluation of learning objectives from the VRLE in the RCT and mixed methods study. This provided continuity of assessment throughout this body of work, which allows us to draw comparisons and conclusions. Future use of these validated outcome instruments would allow researchers to gather information in a systematic manner on the learning experience.

Furthermore, from the extensive research carried out during the course of this thesis, I found that there are very few studies that formerly evaluate the side-effect profile of VR headset use. There is a paucity of research in the literature on the rate of

cybersickness, so this made it difficult to compare at an international level. The RCT and mixed methods study contribute to the literature significantly in this regard and can provide a basis for future comparisons. Importantly, there were no adverse outcomes reported from the use of the VR headsets, both in the RCT and mixed methods study with midwifery students.

Regarding our cost analysis study there is a clear lack of cost analyses in the literature, which is noticed in most systematic reviews including our systematic review on the use of immersive technologies in medical education. Most studies in the literature refer to the high cost of the immersive technologies but fail to report the costs in detail.

Assessing costs in education is a complex task as explained in Chapter 5. With the publication of clear guidelines by the Association of Medical Educators in Europe and the Health Information and Quality Authority I was able to conduct a cost analysis. This study contributes to the limited knowledge on the costs of VR educational tools in medical education, which can play a major role informing the relevant stakeholders in the future.

One of the main limitations of the systematic review is the inclusion criteria with regard to VR educational tools. In the literature, I found that the use of the term VR referred to a multitude of technologies. Therefore, I decided to only include immersive VR educational tools. Conversely, as I only included RCTs, the review is not a reflection on all the immersive educational tools that have been developed and are being used in healthcare student education.

Another limitation of the study was the lack of a timeline, which led to a larger search return on articles retrieved in the initial search. On reflection, this could have been

shortened, as I can observe from the study findings that all studies were carried out in the last 10 years only.

There are also limitations in the RCT that this author acknowledges. A limitation of the study design is that the primary outcome was not aligned to assess the strengths of the VR learning tool. Future assessments should include questions on spatial awareness in addition to factual recall. In relation to the results, there was no statistically significant difference in post intervention knowledge scores. There may have been various factors that influenced this result. A high baseline knowledge in pre-test results and familiarity of the pre-intervention test may have influenced learning during the intervention. Furthermore, the heterogeneity of student learning stages could have been an influencing factor. A population of naïve learners at the same learning stage may mitigate this limitation in addition to a longer interval between pre- and post-intervention assessment. However, a key principle of constructivism, which is thought to support learning with VR technology, is that knowledge is constructed by combining prior knowledge with new knowledge. That is why this population was selected as they had a baseline knowledge of the lesson content. Lastly, this author notes that baseline characteristics between the two groups differed which could have increased the risk of chance bias in the analysis of the results. Stratification or minimisation of the groups or adjustment analysis could minimise this effect. However it could be argued that the characteristics in question are not thought to be effect modifiers therefore not requiring adjustment. Other limitations include the fact that this study is based on a single intervention and setting. Furthermore, a larger sample size would provide more robust results in the future.

Lastly, a limitation of the cost analysis is the inability to carry our further analysis such as cost-benefit, cost-effectiveness or a scale up of the costs over a 3-5-year period due to the time limitations and availability of information.

Finally, our VR learning tool can be used to visualise topics in Obstetrics and Gynaecology in 3D and facilitate a positive learning experience, which I can surmise from my research. However it must be acknowledged that alternative immersive educational tools such as AR allow the user to stay present in reality. Realistically, this may be a preferred educational tool in the future, as there can be simultaneous input by the educator and student. I did not have access to the resources to acquire AR educational tools for this thesis.

7.5 Reflection

This thesis would not be complete without commenting on the global pandemic of COVID-19 that has dominated our lives over the last year and a half. Half-way through year one of my MD, I had developed study plans and protocols set out to conduct my various research studies and then a global pandemic paused everything overnight.

The uncertainty of carrying out research fell upon me and various questions ran through my mind. Can I carry on with my research? Is it safe to still carry out my research? Will I finish my research in time? I had to rethink and revise how I would conduct my randomised control trial and mixed methods study, when it became temporarily safe to do so in the summer and autumn of 2020.

I put the appropriate safety measures in place under strict government guidance during the studies conducted as described in Chapter 3 and 4. This included appropriate hand and respiratory hygiene i.e. facemasks and hand sanitiser, in addition to applying safe social distancing during the study. I advertised the study online, emailed information and consent forms and made the assessment tools available online via QR codes, so that participants could use their own mobile phones to access the evaluation and reduce the risk of exposure.

No participants contracted COVID-19 during the running of the studies carried out. The pandemic also made me realise the potential value of VR technology. A VR headset is the same price as an iPhone if not cheaper now in the current market, students could, conceivably, have a VR headset at home and practice taking a history from a virtual patient when they can't do it in real life. On reflection, I can see that the pandemic was an experience through which I learned invaluable research skills in conjunction with managing uncertainty and adaptation.

7.6 Future research questions

Throughout the course of this thesis, I have identified numerous areas of interest for future research on immersive educational tools in healthcare education. I have summarised these below:

- In Chapter 2, I note that the findings of our systematic review pertain to the healthcare student population and reflect the results of similar reviews investigating postgraduate healthcare professional education. Future studies should perhaps focus on immersive tools that have already been implemented into the medical curriculum to evaluate the learning outcomes on a larger scale and over a longer period of time.
- In Chapter 3, the study findings of the RCT demonstrate that knowledge gain is similar between VRLEs and traditional tutorials, students appreciate the ability to visualise topics in 3D and enjoy the learning experience of a VRLE. Secondary outcomes relating to the learning experience require further validation. If I were to carry out this study again, I would ensure that the learning objectives align with the strengths of VR learning tools i.e ability to enhance spatial awareness of complex 3D concepts. I recommend that future trials should be carried out with larger sample sizes and power calculations based on our secondary outcomes as discussed. Future research should also focus on evaluating the learning objectives of AR or MR tools that may perhaps have more benefits than VR.
- In Chapter 4, I carried out a mixed methods study with Midwifery students assessing the use of a VRLE on the topic of "*Fetal lie, position and presentation in pregnancy*". Future research should involve RCTs in this population to explore the effectiveness of VRLEs further.

- In Chapter 5, results from the cost analysis contribute to the current research on VR learning tools and inform comparisons for future research. It may inform relevant stakeholders in the future which may lead to the implementation of VR learning tools into the medical curriculum. However further studies involving a cost benefit analysis will provide a more in-depth analysis of the feasibility of VR learning tools in the medical education setting.
- In Chapter 6, a case study proposes how VR could be used as a patient education tool in the diagnosis of congenital abnormalities. Future research should include a case series assessing the use of the VRLE as an educational tool for patients. Complex diagnosis can be difficult for the patient to understand; therefore a 3D learning tool could help the patient visualise the abnormality and assist in patient education.

7.7 Conclusion

In conclusion, the research findings of this thesis are exciting and novel. We successfully developed a VRLE, guided by a structured VRID model informed by educational and multimedia learning theories. The VR lesson was guided by a conceptual framework supported by principles of constructivism and experiential learning theories. The research findings presented in this thesis have provided us with a greater understanding of how VRLEs can be used to support learning within Obstetrics and Gynaecology education. Our research findings on the learner experience, side effect profile and costing of our VR learning tool contribute significantly to the current research base on immersive technologies in medical education and inform future research in the area of medical education and beyond. Despite immersive technologies being around for some time, their use in healthcare education is still in its infancy today and requires further research to validate and build a strong evidence base for its use. However, a question that remains for further consideration is whether this fun new way of engaging learners is worth the side effect profile and development costs. Implementing change in education is a challenging process and should involve informed evidence-based research. To quote David Warlick, a prominent educator, author, and promoter of technology in the classroom:

> "*I need technology in every classroom and in every student and teachers' hand, because it is the pen and paper of our time, and it is the lens through which I experience most of our world"* – David Warlick (Lathan, 2022).

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Appendices

Appendix 1: Information Leaflet and Consent

The National Maternity Hospital

Founded in 1894

Holles Street, Dublin 2.

Telephone: (01) 6373100. Fax: 6766623. Web: www.nmh.ie

Master: Prof Shane Higgins

Information Leaflet :

Investigating the Role of Virtual and Augmented Reality in Healthcare Education

Principal Investigator: Prof Fionnuala McAuliffe

Co-Investigators: Dr Grace Ryan

Prof Mary Higgins

Prof Eleni Mangina

You are invited to participate in an exciting and innovative research study, which is explained below. It is important to read this information leaflet in order to understand why we are conducting this research study and collecting this data and what it will involve for you. Please take your time to read through this information leaflet carefully. If you have any questions, please do not hesitate to ask the study doctor/research staff for further clarification.

What is the research project about?

This research project is investigating the use of virtual reality and how this technique may help learning in medical, nursing and midwifery education. Firstly, it is important to understand what virtual reality (VR) and augmented reality (AR) mean. VR can be defined as "real-time interactive graphics with 3D Models". VR provides opportunities to develop new educational tools for both patients and health care professionals. Augmented reality is by comparison an interactive experience of a real-world environment where the objects that reside in the real world are "augmented" by computer-generated perceptual information. This study is taking

place to find out whether new technology like VR and AR can help students understand foetal and maternal anatomy as these so-called invisible concepts, are often reported by students as difficult to grasp. The study will involve you using virtual or augmented reality to learn about various other topics in the area of obstetrics and gynaecology. You will be asked to complete a basic pre- and post-study MCQ and fill out a questionnaire on your learning experience and your experience of the VR/AR educational tool.

Why am I being asked to participate in this research project?

We are inviting all students from UEM/GEM Medicine at UCD School of Medicine and students from UCD School of Nursing, Midwifery and Health Systems to take part. We are asking you to participate as we are investigating the educational value of new educational technology such as virtual and augmented reality. From previous studies, research is suggesting that educational technologies, specifically immersive technologies may provide an enhanced learning and understanding of certain educational topics, especially invisible concepts such as those found, in obstetrics and gynaecology. We would like to explore this more through this research project.

What will my role be in this research project?

If you consent to participate, you will have the opportunity to use virtual or augmented reality and engage with 3D embryological and anatomical models based on standard topics within the obstetrics and gynaecology curriculum. This study will take place in a classroom in UCD or the National Maternity Hospital. Participation will involve a tutorial with a virtual or augmented reality headset and learning about topics in embryology and obstetrics and gynaecology. It will be a learning experience that will last approximately 15 minutes. We will provide instructions on the use of the VR/AR headsets and a debriefing session will be held after the learning experience. You can take part in the study multiple times if you so wish, during your degree. Evaluation will consist of a pre- and post-study MCQ, along with a post study questionnaire on your learning experience as we would like to hear your opinions and attitudes on the use of this technology for learning purposes. If you would like to take part or find out further information, you can express your interest by emailing the following email address grace.ryan@ucd.ie. You will receive instructions on the date, time and location of the study along with the information leaflet.

Is there a benefit to me or, will there be potential benefits to improve future medical care?

There is a learning opportunity for the participant to see the foetal anatomy in 3D, topics pertaining to the third trimester of pregnancy and birth, complementing the teaching given in modules at UCD. Your views, and experiences are important to help us to develop new and innovative ways to provide medical education. There will be no impact on your academic standing whether you choose to participate in the study or not. Ultimately, we hope to gain information, which will be used to improve future patient education and training of health care professionals, which includes medical students.

Are there any risks involved?

There are no known potential serious risks or harm involved with the study. Commonly reported side effects of prolonged use of 3D headsets include eye strain and headaches. However, the intervention involving headsets in this research study will be set to a 15-minute experience to minimise this risk. If you have any medical problems such as epilepsy, pre-existing binocular vison disturbances or psychiatric disorders or suffer from a heart condition or other serious medical conditions, you will not be permitted to participate in the study as this is a safety precaution advised by the manufacturers. Before taking part in the study you will be screened for any medical conditions mentioned above, you will be asked if you have any medical problems and if you have any of the conditions mentioned above you will not be permitted to participate in the study.

Confidentiality

We will need to collect your student number, as identification in a recruitment log and assign you a study number for the duration of your participation in the study. This information is required for pre- and post-study MCQ evaluation. Once the participant has completed the study which will include pre- and post-study questionnaires their student number will be removed, and all data will be anonymous. All research data collected in the study will be stored according with UCD regulations to a secure password protected UCD Google drive, hard copies of data collected will be stored in a locked drawer in a locked office in the Perinatal research centre at the National Maternity Hospital, which requires swipe access.

Do I have to take part?

Your participation in this study is entirely voluntary and you should feel under no pressure to consent. Whether you decide to take part or not it will have no implications on your academic standing.

How can I withdraw from the study?

If you would like to withdraw from the study at any point for any reason, you can contact us directly by emailing grace.ryan@ucd.ie. If you would like to withdraw from the study at any point, there will be no implications on your academic standing.

At the completion of the project, will I be informed of the research outcome?

If you would like to be informed about the outcomes of this research study, please let a member of the research team know.

What happens if I have further questions, concerns or complaints regarding the study?

If you have any further questions or need clarification, a member of the research team - Dr Grace Ryan 01 637 3100, will be happy to assist you Mon-Fri 8am-4pm or alternatively you can email us directly at grace.ryan@ucd.ie.

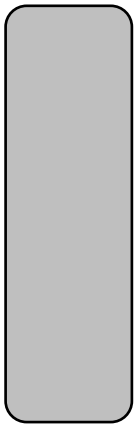
Consent Form

Initials only

1. I _____ confirm that I voluntarily agree to participate in this research. ☐

2. I confirm that I have read and understood the information leaflet attached. I have had the opportunity to consider the information ask questions and have had these answered satisfactorily. ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected. ☐



_____	_____	_____
Name of Participant	Date	Signature

Appendix 2: MCQ for Randomised Control Trial with Medical Students

The National Maternity Hospital

Founded in 1894

Holles Street, Dublin 2.

Telephone: (01) 6373100. Fax: 6766623. Web: www.nmh.ie

Please answer the following questions based on the learning

1. Which type of breech presentation is described as both legs flexed at the hips and knees?

    a. Complete Breech
    b. Frank Breech
    c. Extended Breech
    d. Footling Breech
    e. Cephalic

2. What type of presentation is most suitable for a vaginal birth?

    a. Cephalic
    b. Footling Breech
    c. Brow
    d. Face
    e. Shoulder

3. How can we describe the condition known as placenta praevia?
    a. Anterior placenta
    b. Posterior placenta
    c. Fundal placenta
    d. Placenta covering or partially covering the internal cervical os
    e. Placenta invading into the myometrial tissue

4. Which of the following is a known complication associated with placenta previa?

    a. Placental abruption
    b. Antepartum haemorrhage
    c. Infection
    d. Assisted reproductive technology
    e. Oligohydramnios

5. What is the most common position of the fetal head at birth?

    a. Occipito-anterior
    b. Occipito-posterior
    c. Right Occipito-transverse
    d. Occipito-oblique
    e. Left Occipito-transverse

6. Unstable lie is:

    a. The same as a transverse lie
    b. A type of abnormal position
    c. Corrected by “external cephalic version” only
    d. A fetal lie where 85% of cases revert to a longitudinal lie spontaneously
    e. Is an abnormal presentation in early pregnancy

7. When the fetal buttocks is the presenting part, this is known as:

    a. Complete Breech
    b. Frank Breech
    c. Extended Breech
    d. Footling Breech
    e. Brow Presentation

8. What risks are associated with breech presentation?
    a. Placenta previa
    b. Cord Prolapse
    c. Placenta abruption

d. Preeclampsia
e. Rupture of membranes

9. What are the current guidelines on the management of the delivery of a breech presentation?

a. External Cephalic Version
b. Caesarean Section
c. Vaginal breech birth
d. No guidelines
e. Fully dilated caesarean section

10. What does fetal presentation refer too?

a. Diameter of fetal head
b. Fetal part that is leading the way out through the birth canal
c. The way the fetus is lying in the womb
d. The way in which the fetal head is turned in the pelvis
e. The way in which the fetal legs are presenting

11. In which week do we expect to see the fetal heartbeat?

a. Week 4
b. Week 6
c. Week 8
d. Week 12
e. Week 14

12. At what gestation does the neural tube close?

a. Week 5
b. Week 6
c. Week 7
d. Week 10
e. Week 20

13. Failure of the neural tube to close could cause which abnormality?

a. Spina bifida
b. Scoliosis
c. Ventriculomegaly
d. Sacrococcygeal teratoma
e. Congenital Diaphragmatic Hernia

14. What is the most common type of spina bifida?

a. Spina bifida occulta
b. Meningocele
c. Myelomeningocele
d. Hydrocephalus
e. Anencephaly

15. If midgut herniation fails to close, what abnormality does it result in?

a. Congenital diaphragmatic hernia
b. Omphalocele
c. Duodenal atresia
d. Pulmonary hypoplasia
e. Coarctation of the aorta

16. When does the placenta start functioning?

a. Week 8
b. Week 10
c. Week 12
d. Week 18
e. Week 30

17. At what stage can you determine the sex of the foetus?

a. Week 10
b. Week 12
c. Week 14
d. Week 16
e. Week 18

18. When do upper and lower limb buds develop?

a. Week 4
b. Week 8
c. Week 10
d. Week 12
e. Week 14

19. How do we measure the length of the fetus in the first trimester?

a. Crown Rump Length
b. Fetal Biometry
c. Crown Limb Length
d. Take the measurement from the maximum length of the fetus
e. Femur length

20. At what gestation are the lungs considered developed?

a. 28 weeks
b. 32 weeks
c. 34 weeks
d. 36 weeks
e. 37 weeks

Appendix 3: Learning Experience Student Questionnaire

The National Maternity Hospital

Founded in 1894

Holles Street, Dublin 2.

Telephone: (01) 6373100. Fax: 6766623. Web: www.nmh.ie

Instructions: Please fill in the following basic demographic information and, if possible, please answer the questions below about your learning experience. The first part of the questionnaire contains some basic questions on demographics. The second and third part of the questionnaire contain a series of statements about your personal attitudes and views with regard to the learning experience you received. Each item represents a statement about your attitude toward your satisfaction with learning and self-confidence in obtaining the instruction you need. There are no right or wrong answers. You will probably agree with some of the statements and disagree with others. Please indicate your own personal feelings about each statement below by marking the numbers that best describe your attitude or beliefs. Please be truthful and describe your attitude as it really is, not what you would like for it to be.

1. Which learning experience did you participate in?

Virtual Reality ☐ Traditional Lecture ☐

2. What is your gender?

Male ☐ Female ☐ Prefer not to say ☐

3. Please indicate which programme (UEM or GEM) and Stage of degree you are:

Undergraduate Entry Medicine ☐ Graduate Entry Medicine ☐

Stage:

1	
2	
3	
4	
5	
6	

4. Please indicate which age category applies to you:

18-24 ☐ 25-34 ☐ 35-45 ☐ 45+ ☐

5. Do you know what virtual reality is? Yes ☐ No ☐

If yes, can you please give an explanation?

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6. Do you know what augmented reality is? Yes ☐ No ☐

If yes can you please give an explanation?

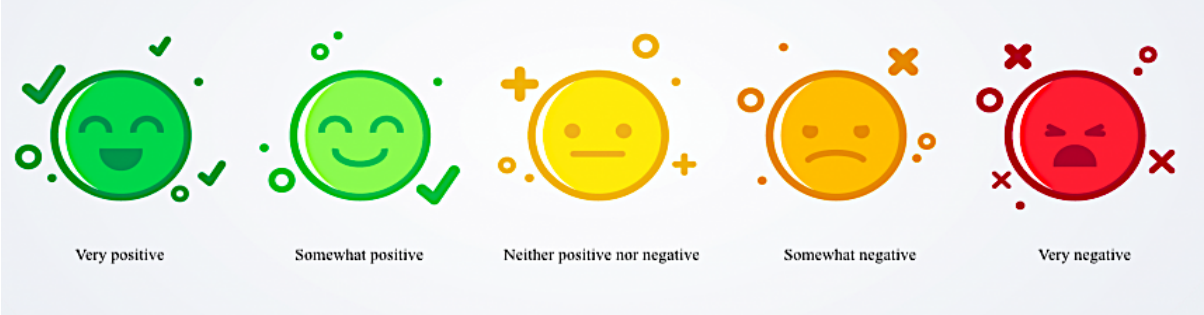
7. Have you ever used virtual or augmented reality before, e.g. in a learning or gaming experience?

Yes ☐ No ☐

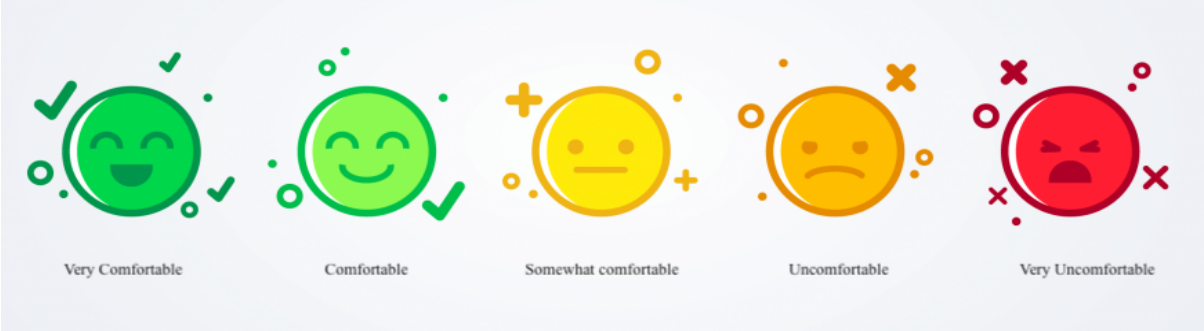
If yes, can you provide further details on the device used or experience?

8. Do you have any other comments to add to your learning experience today?

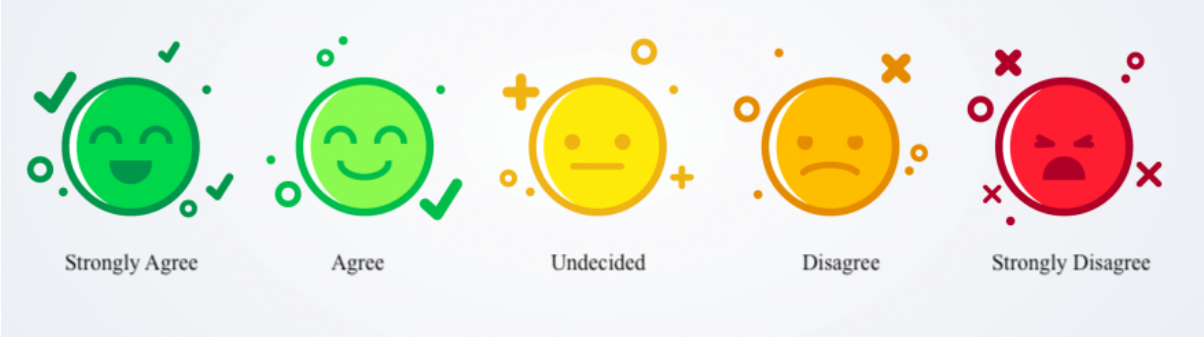
9. How would you rate your learning experience today? Please circle your answer.



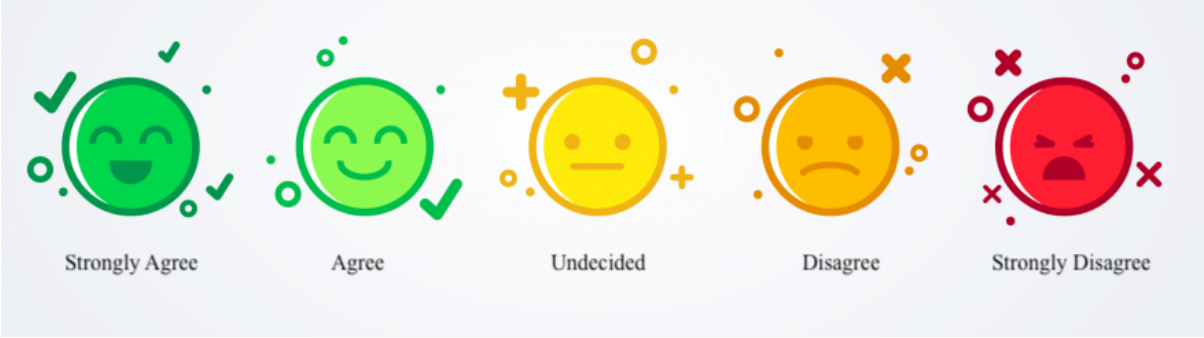
10. Please rate on the scale below of how comfortable you felt in the learning environment today.



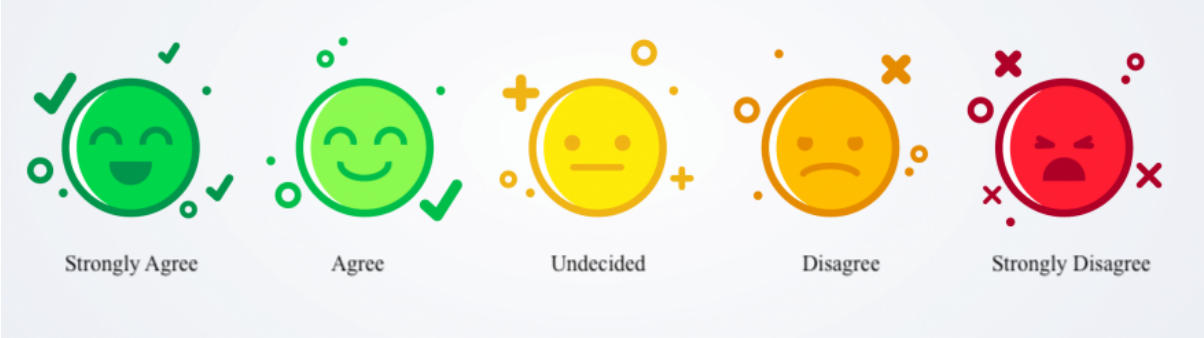
11. The teaching methods used in this learning experience were helpful and effective.



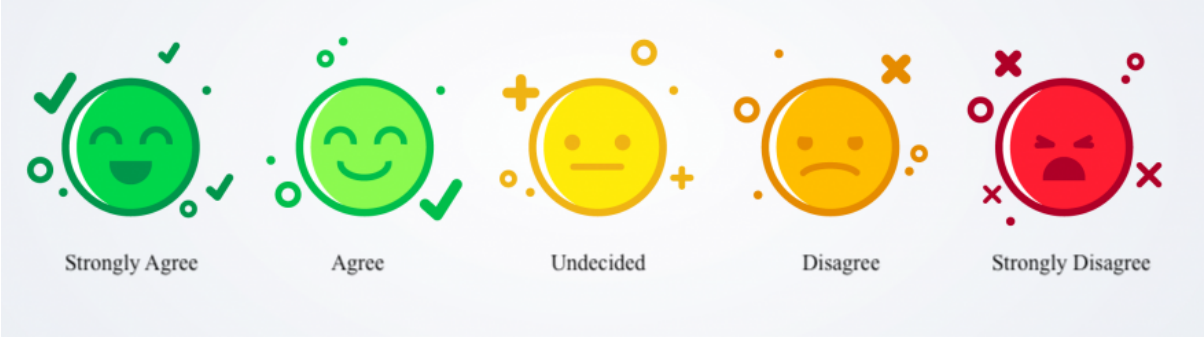
12. This experience provided me with a variety of learning materials and activities to promote my learning of difficult topics in the obstetrics and gynaecology curriculum.



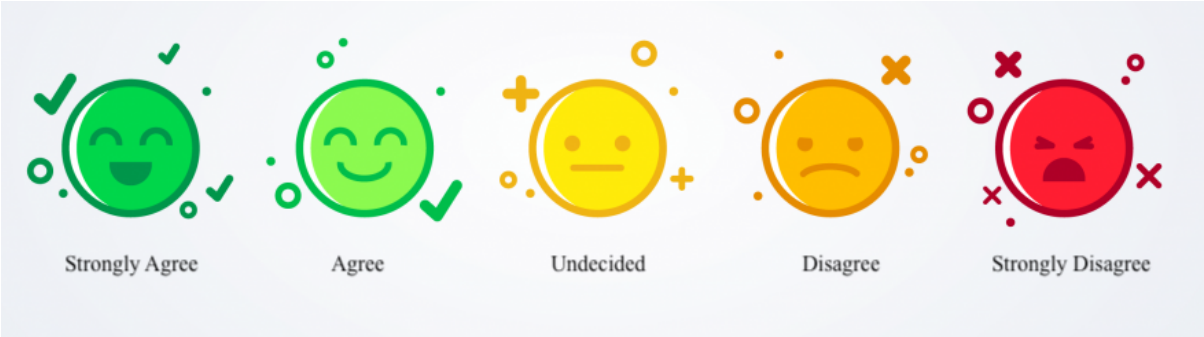
13. I enjoyed how the learning experience was taught.



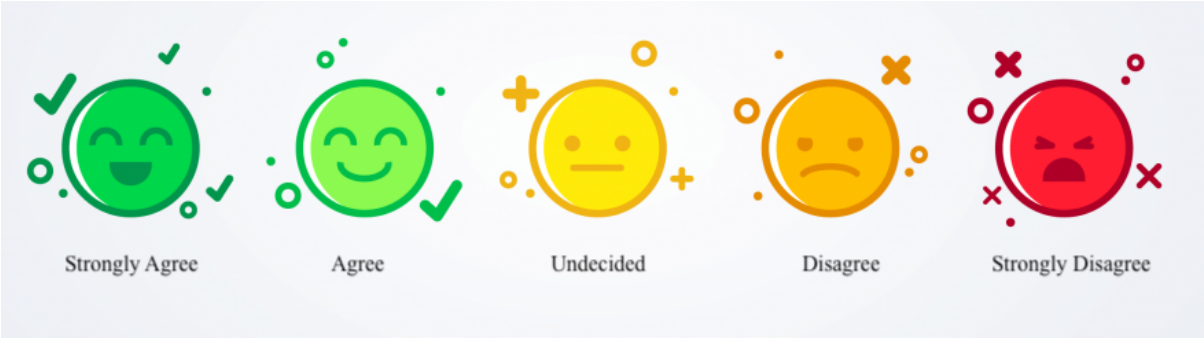
14. The teaching materials used in this learning experience were motivating and helped me to learn.



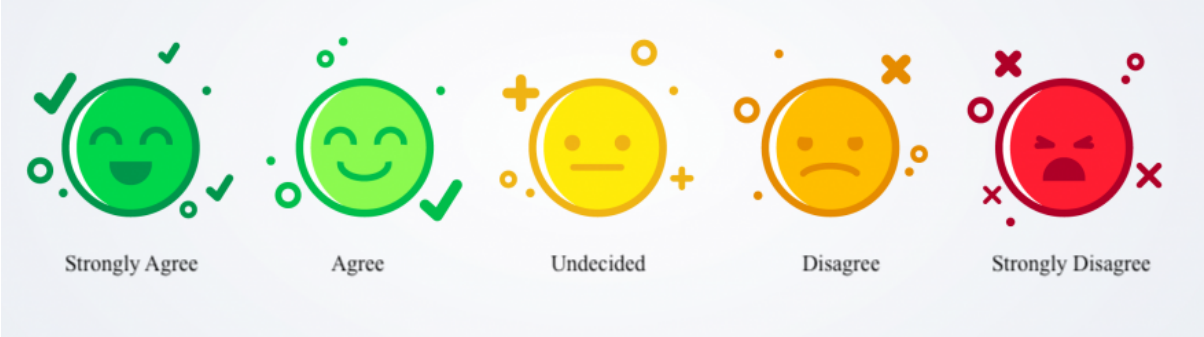
15. The way the topic was taught was suitable to the way I learn.



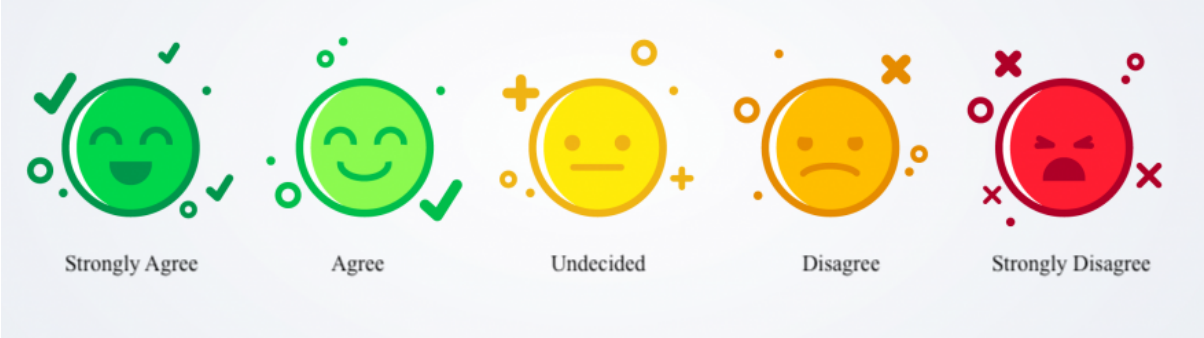
16. I am confident that I am mastering the content of the learning experience that my instructors presented to me.



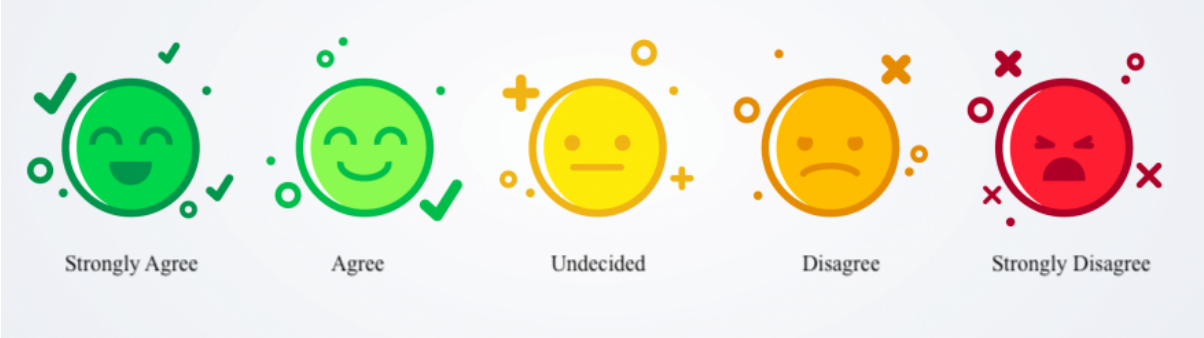
17. I am confident that this learning experience covered complex content necessary for the mastery of topics in the Obstetrics and Gynaecology curriculum.



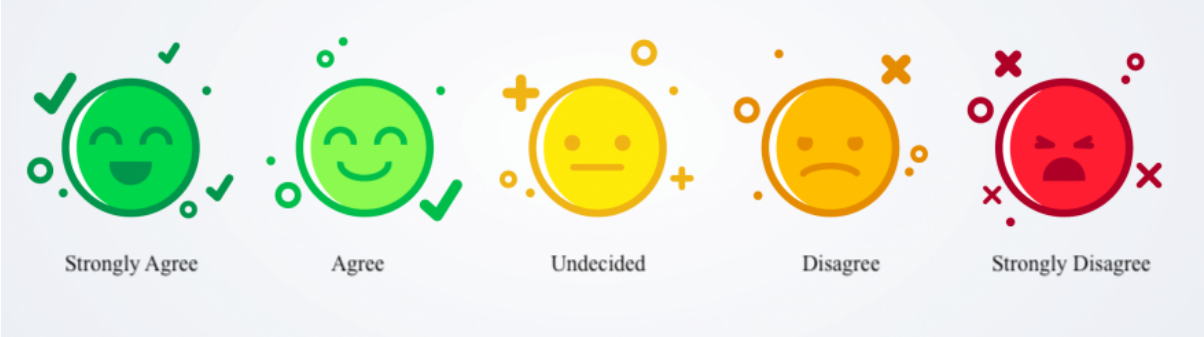
18. I am confident that I am developing the skills and obtaining the required knowledge from this learning experience to perform necessary tasks in a clinical setting.



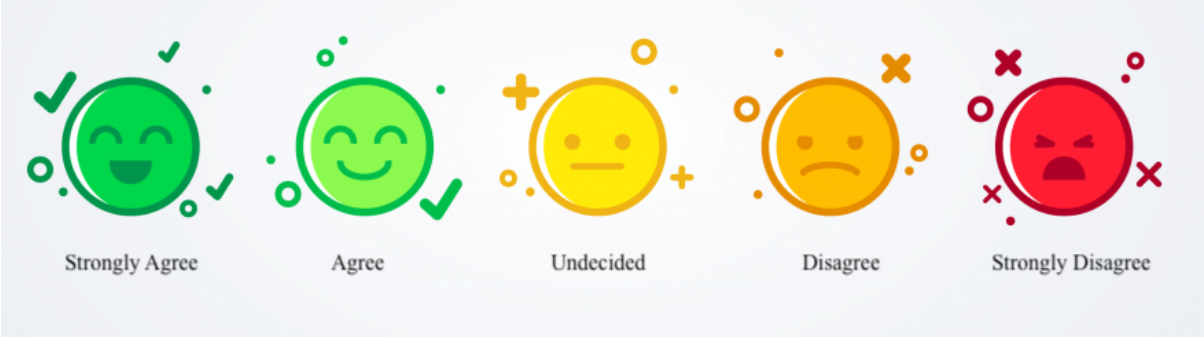
19. My instructors used helpful resources to enhance the learning of this content.



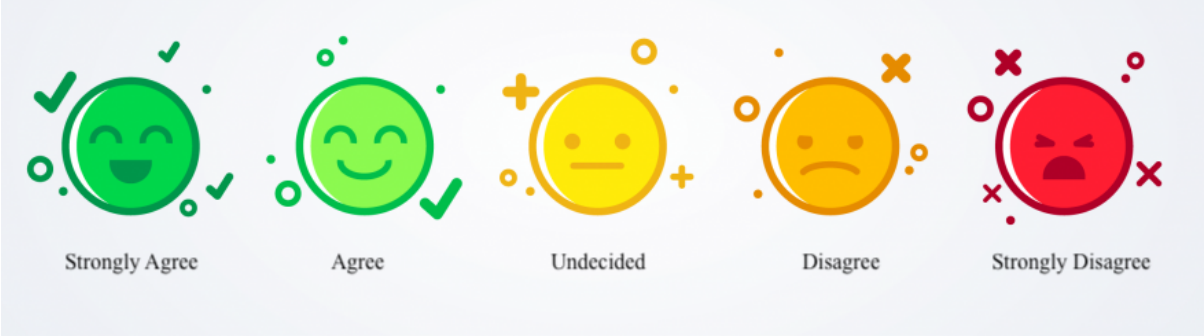
20. It is my responsibility as the student to learn what I need to know from this learning experience.



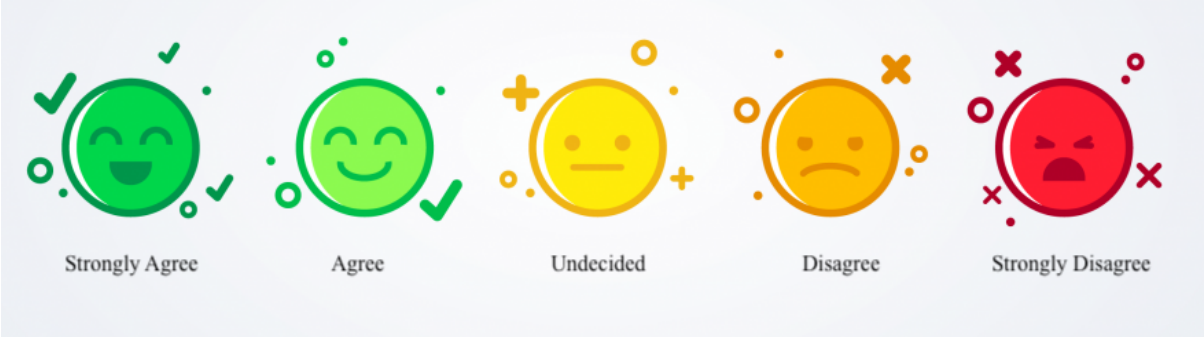
21. I know how to get help when I do not understand the concepts covered in the learning experience.



22. I know how to use the learning experience to learn helpful clinical skills.



23. It is the instructor's responsibility to tell me what content I need to learn during the learning experience.



Appendix 4: Virtual Reality Design Questionnaire

The National Maternity Hospital

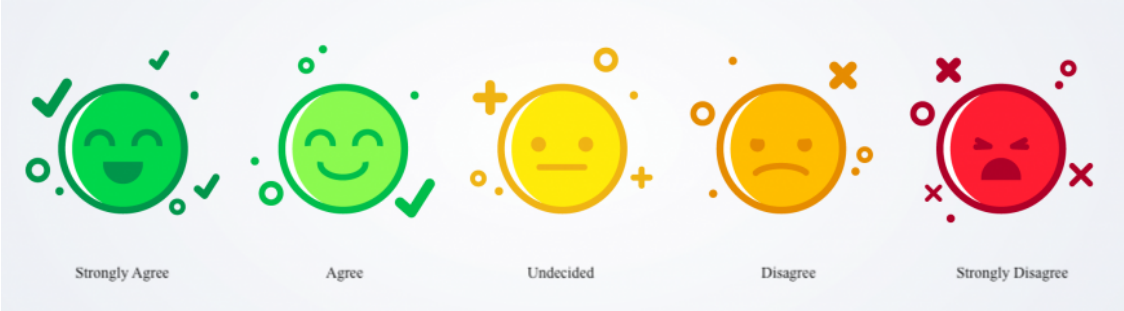
Founded in 1894

Holles Street, Dublin 2.

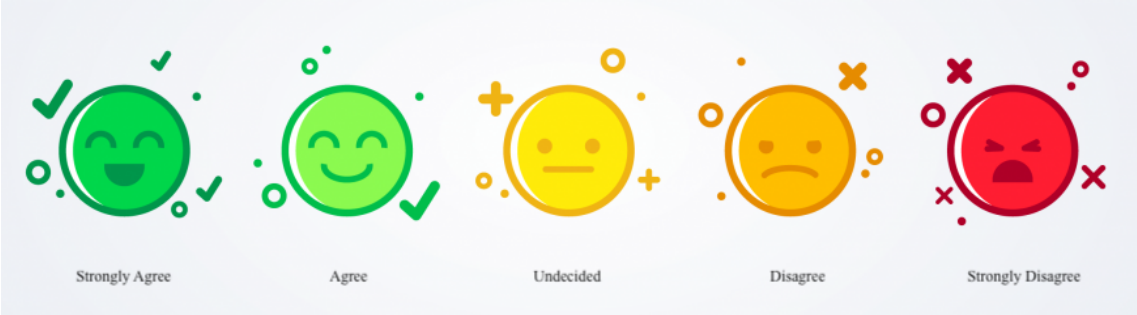
Telephone: (01) 6373100. Fax: 6766623. Web: www.nmh.ie

Instructions: In order to measure if the best immersive technology design elements were implemented in your virtual reality learning experience, please complete the survey below by circling how you feel in relation to the statements below.

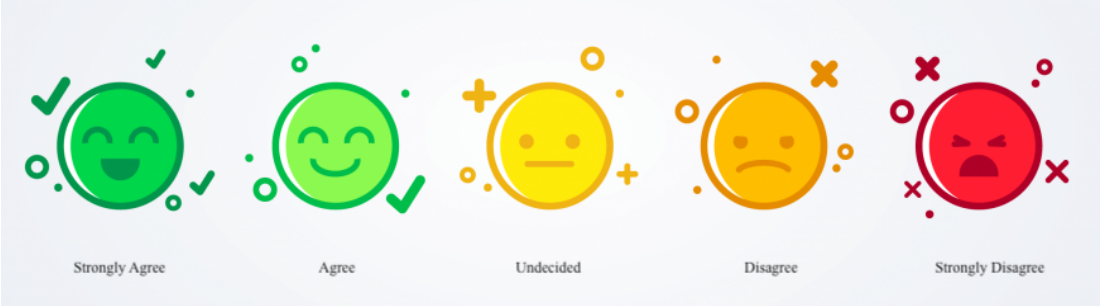
1. The virtual reality headset was easy to use.



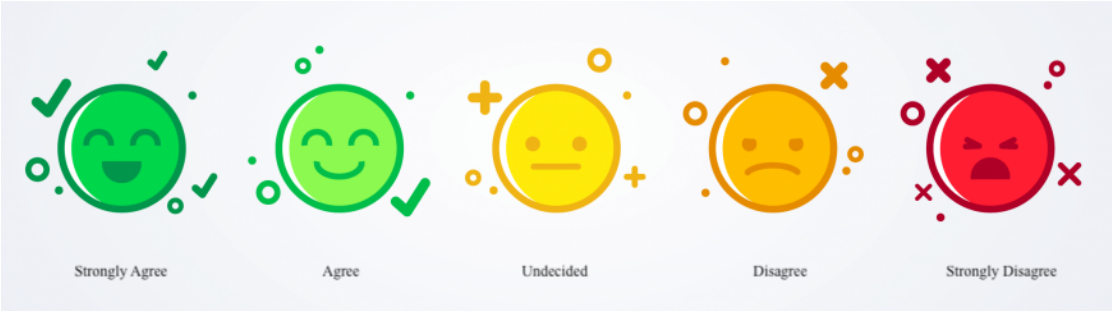
2. The virtual reality headset was comfortable to wear.



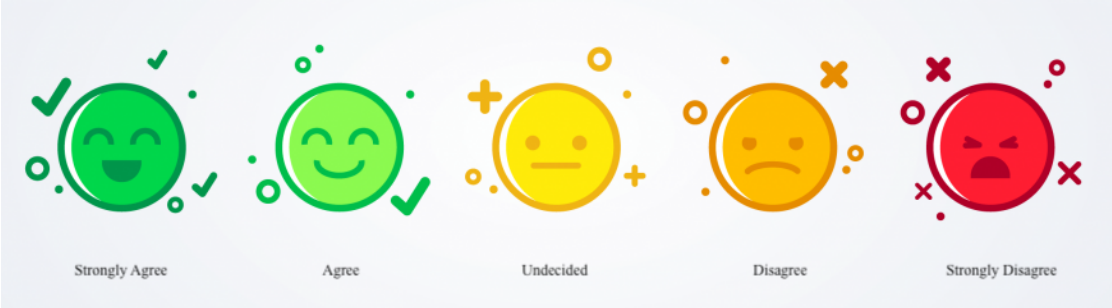
3. There was enough information provided at the beginning of the virtual reality learning experience to provide direction and encouragement.



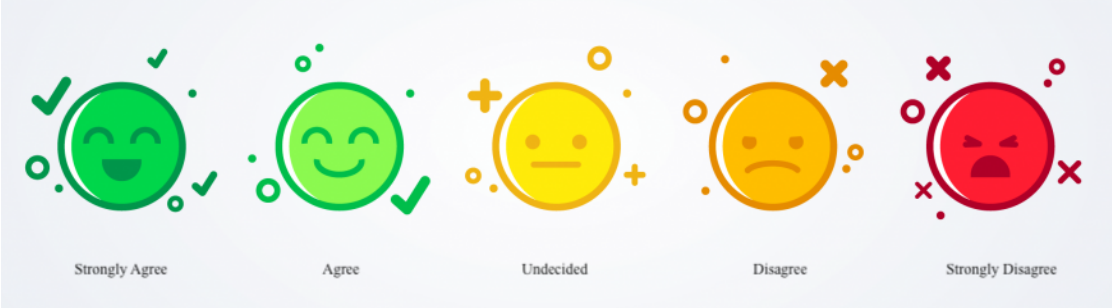
4. I clearly understood the purpose and objectives of the virtual reality learning experience.



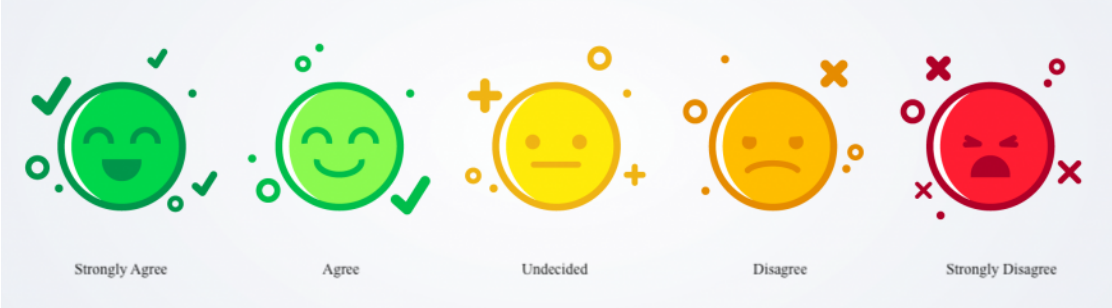
5. The virtual reality learning experience provided enough clear information for me.



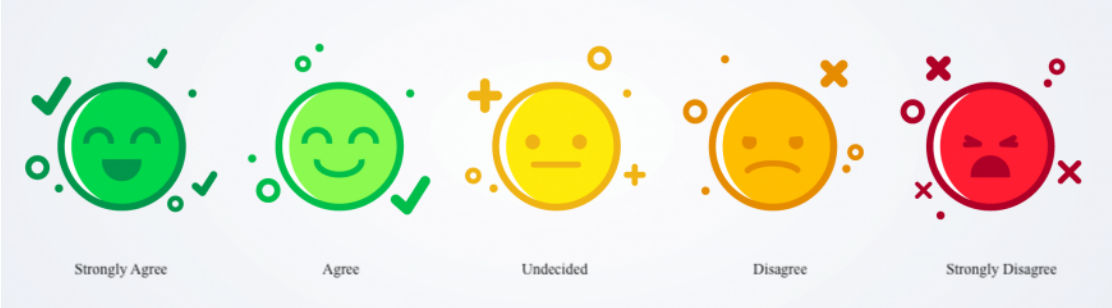
6. Adequate information was provided to me to use the virtual reality headset.



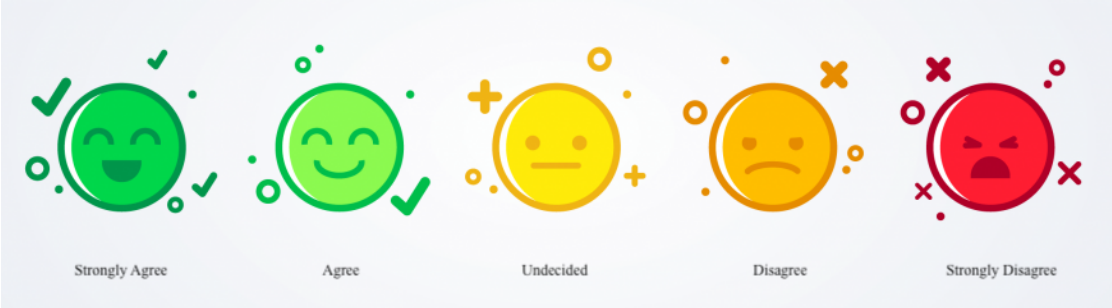
7. The cues were appropriate and geared to promote my understanding.



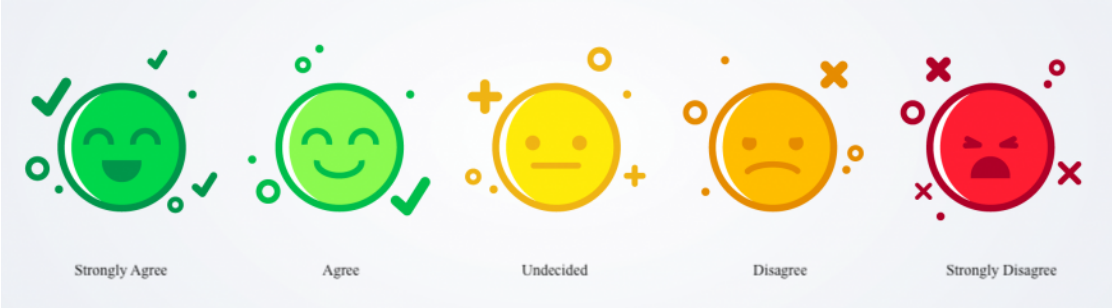
8. Support was offered in a timely manner.



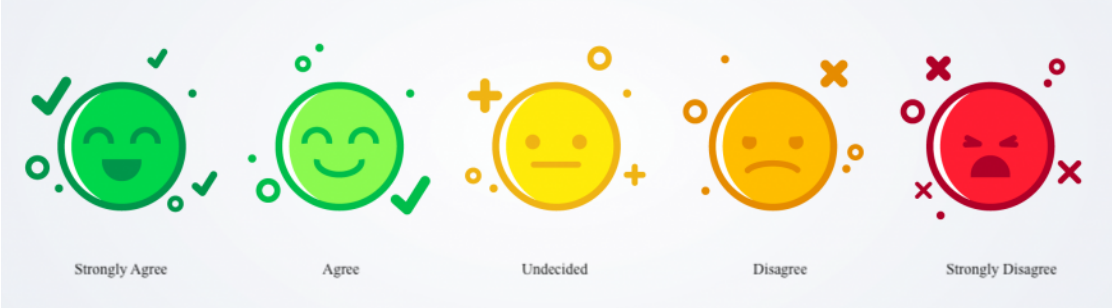
9. My need for help was recognized.



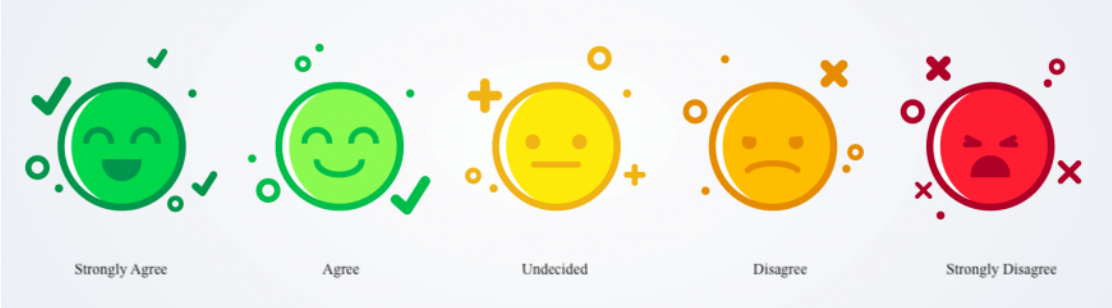
10. I felt supported by the teacher's assistance during the virtual reality learning experience.



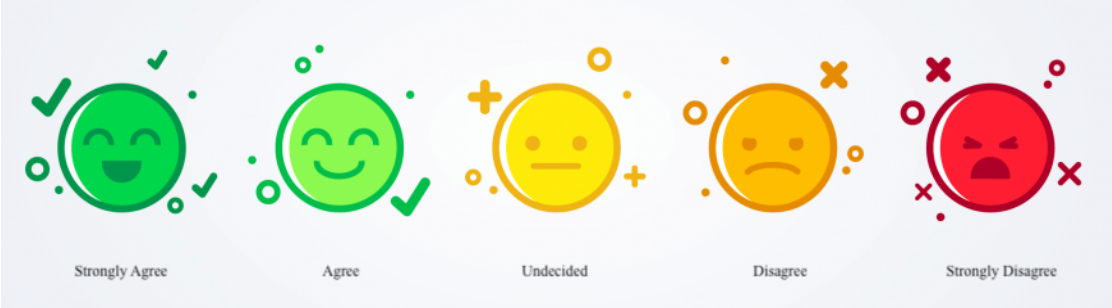
11. I was supported in the learning process.



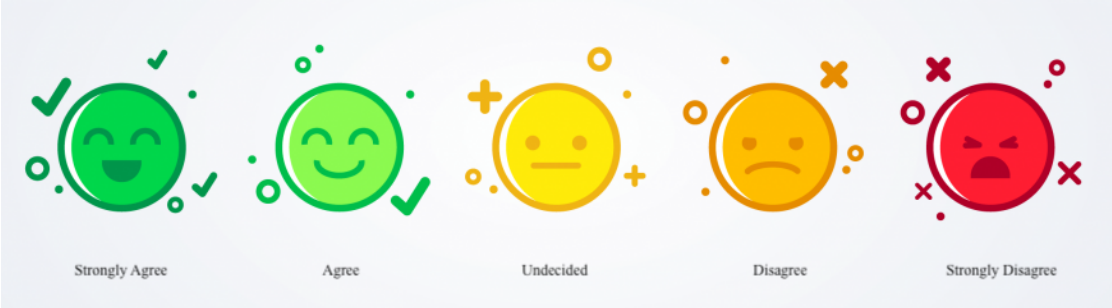
12. Independent problem-solving was facilitated.



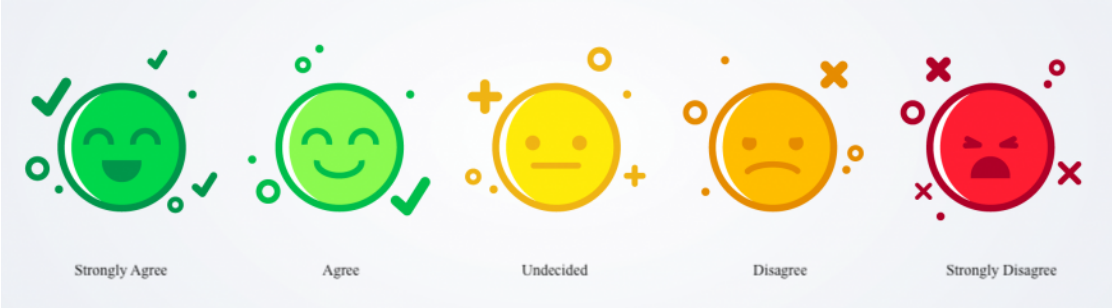
13. The virtual reality learning experience was designed for my specific level of knowledge and skills.



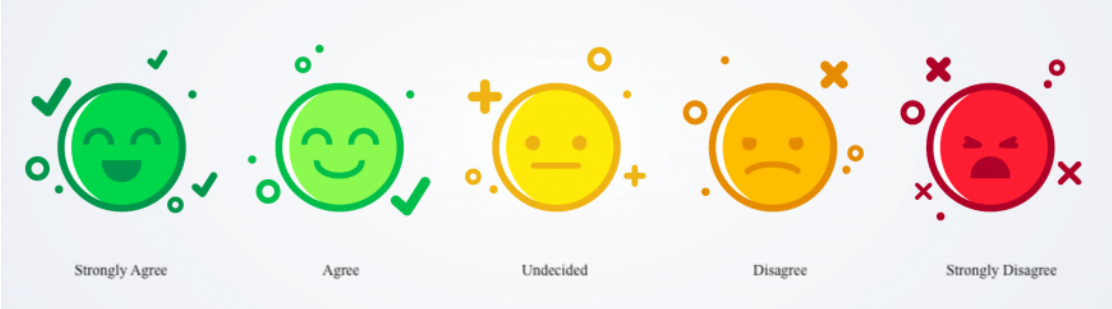
14. The virtual reality learning experience allowed me the opportunity to enhance my understanding of invisible concepts in embryology and/or fetal anatomy which are often difficult concepts to grasp.



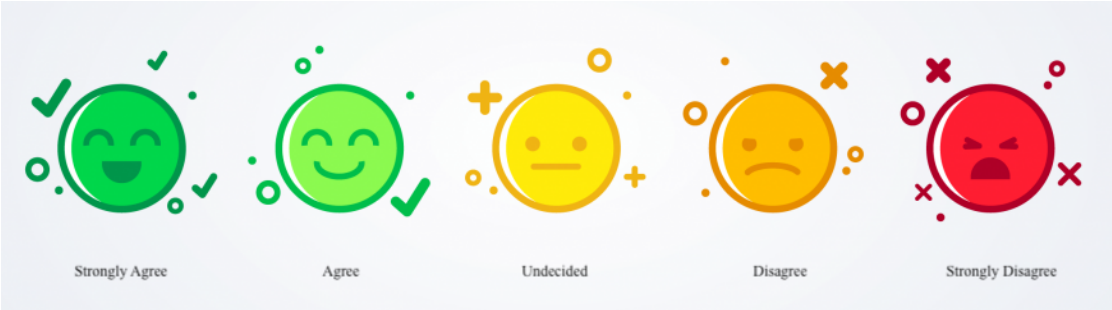
15. Feedback provided was constructive.



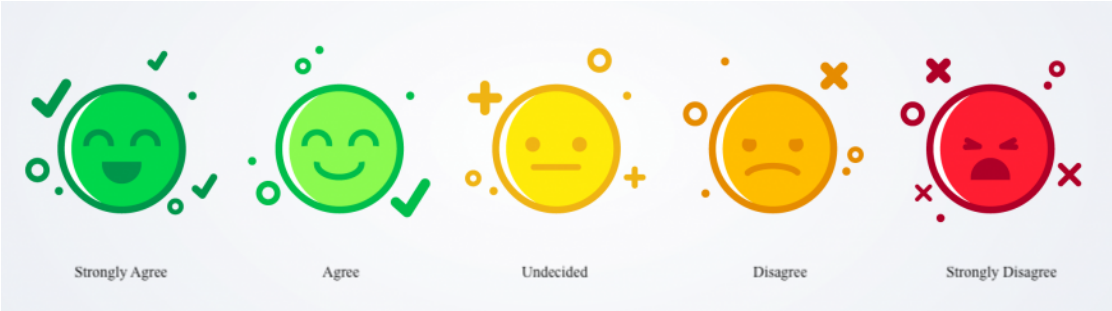
16. Feedback was provided in a timely manner.



17. There was an opportunity after the learning experience to obtain feedback from the teacher in order to build knowledge to another level.



18. The virtual reality learning experience was very realistic.



19. How would you feel about incorporating the use of VR headsets as a learning tool in the classroom?

20. Did you experience any side effects from use of the headset mentioned below today?

- Dizziness ☐
- Headache ☐
- Blurred/Altered or Double vision ☐
- Loss of awareness ☐
- Eye strain ☐
- Eye or muscle twitching ☐
- Involuntary moving ☐
- Disorientation ☐
- Impaired balance ☐
- Impaired hand-eye coordination ☐
- Excessive sweating ☐
- Increased salivation ☐
- Nausea ☐
- Light-headedness ☐
- Discomfort or pain in the head or eyes ☐
- Drowsiness ☐
- Fatigue ☐
- Any symptoms similar to motion sickness ☐

Appendix 5: Information Leaflet and Consent: Investigating the Role of Virtual Reality in Patient Education

The National Maternity Hospital

Founded in 1894

Holles Street, Dublin 2.

Telephone: (01) 6373100. Fax: 6766623. Web: www.nmh.ie

Master: Prof Shane Higgins

Principal Investigator: Prof Fionnuala McAuliffe

Co-Investigators: Dr Grace Ryan

Dr. Dan Kane

Prof Mary Higgins

Prof Eleni Mangina

You are invited to participate in an exciting and innovative research study, which is explained below. It is important to read this information leaflet in order to understand why we are conducting this research study and collecting this data and what it will involve for you. Please take your time to read through this information leaflet carefully. If you have any questions, please do not hesitate to ask the study doctor/research staff for further clarification.

What is the research project about?

This research project is investigating the use of virtual reality and how this technology may help to enhance patient education about pregnancy and medical conditions related to pregnancy. Firstly, it is important to understand what virtual reality (VR) means. VR can be defined as "real-time interactive graphics with 3D Models using a head-mounted display". VR provides opportunities to develop new educational tools for both patients and health care professionals. This study is taking place to find out whether new technology like VR can help mothers understand what the baby looks like inside the womb. The study will involve you using virtual reality to learn about what a baby looks like inside the womb. You will be asked

to complete a basic pre- and post-study MCQ and fill out a questionnaire on your experience using the VR headset.

Why am I being asked to participate in this research project?

We are inviting all patients that have are attending the fetal medicine unit for care in their pregnancy. We are asking you to participate as we are investigating the educational value of virtual reality to help increase understanding further in mothers that have had a diagnosis of a congenital abnormality. From previous studies, research is suggesting that educational technologies, specifically immersive technologies may provide an enhanced learning and understanding of medical conditions that are hard to visualize. We would like to explore this more through this research project.

What will my role be in this research project?

If you consent to participate, you will have the opportunity to use virtual reality and engage with a 3D model of a baby with a congenital abnormality. This study will take place the fetal assessment unit at the National Maternity Hospital. Participation will involve putting on the VR headset where you will be immersed into a 3D world where you can visualise and interact with the 3D model of the baby. It will be a learning experience that will last approximately 15 minutes. We will provide instructions on the use of the VR/AR headsets and a debriefing session will be held after the learning experience. Evaluation will consist of a pre- and post-study MCQ, along with a post study questionnaire on your learning experience as we would like to hear your opinions and attitudes on the use of this technology for learning purposes. If you would like to take part or find out further information, you can express your interest by emailing the following email address grace.ryan@ucd.ie. You will receive instructions on the date, time and location of the study along with the information leaflet.

Is there a benefit to me or, will there be potential benefits to improve future medical care?

There is a learning opportunity for mothers to see the anatomy of the baby in 3D, that may help enhance the understanding of a congenital abnormality. Your views, and experiences are important to help us to develop new and innovative ways to improve patient education. There will be no impact on your care during pregnancy whether you choose to participate in the study

or not. Ultimately, we hope to gain information, which will be used to improve future patient education and training of health care professionals.

Are there any risks involved?

There are no known potential serious risks or harm involved with the study. Commonly reported side effects of prolonged use of 3D headsets include eye strain and headaches. However, the intervention involving headsets in this research study will be set to a 15-minute experience or less to minimise this risk. If you have any medical problems such as epilepsy, pre-existing binocular vison disturbances or psychiatric disorders or suffer from a heart condition or other serious medical conditions, you will not be permitted to participate in the study as this is a safety precaution advised by the manufacturers. Before taking part in the study you will be screened for any medical conditions mentioned above, you will be asked if you have any medical problems and if you have any of the conditions mentioned above you will not be permitted to participate in the study.

Confidentiality

We will need to collect your patient identification number, as identification in a recruitment log and assign you a study number for the duration of your participation in the study. This information is required for pre- and post-study MCQ evaluation. Once the participant has completed the study which will include pre- and post-study questionnaires their patient identification number will be removed, and all data will be anonymous. All research data collected in the study will be stored according with NMH regulations to a secure password protected NMH Research Google drive, hard copies of data collected will be stored in a locked drawer in a locked office in the Perinatal research centre at the National Maternity Hospital, which requires swipe access.

Do I have to take part?

Your participation in this study is entirely voluntary and you should feel under no pressure to consent. Whether you decide to take part or not it will have no implications on your antenatal care.

How can I withdraw from the study?

If you would like to withdraw from the study at any point for any reason, you can contact us directly by emailing grace.ryan@ucd.ie. If you would like to withdraw from the study at any point, there will be no implications on your antenatal care.

At the completion of the project, will I be informed of the research outcome?

If you would like to be informed about the outcomes of this research study, please let a member of the research team know.

What happens if I have further questions, concerns or complaints regarding the study?

If you have any further questions or need clarification, a member of the research team - Dr Grace Ryan 01 637 3100, will be happy to assist you Mon-Fri 8am-4pm or alternatively you can email us directly at grace.ryan@ucd.ie.

Consent Form

Initials only

4. I _____ confirm that I voluntarily agree to participate in this research. ☐

5. I confirm that I have read and understood the information leaflet attached. I have had the opportunity to consider the information ask questions and have had these answered satisfactorily. ☐

6. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected. ☐

_____	_____	_____
Name of Participant	Date	Signature

Appendix 6: Maternal Attachment Patient Questionnaire

The National Maternity Hospital

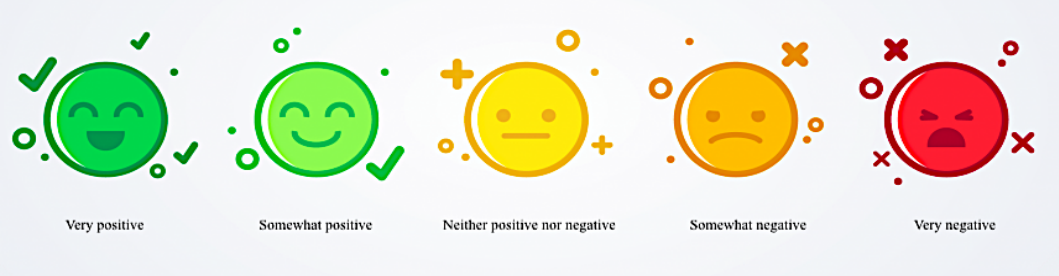
Founded in 1894

Holles Street, Dublin 2.

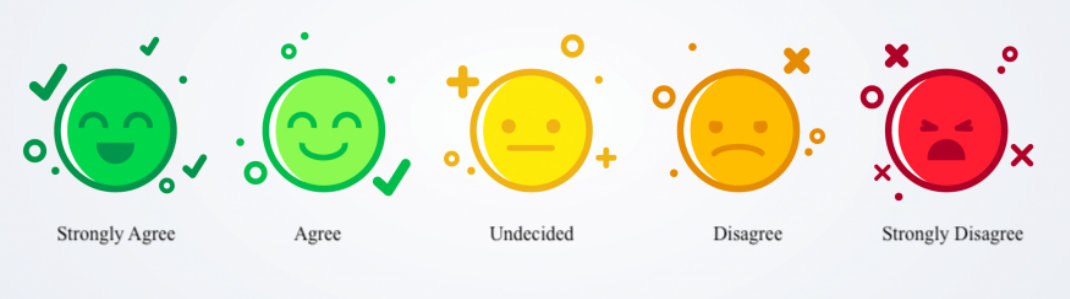
Telephone: (01) 6373100. Fax: 6766623. Web: www.nmh.ie

Master: Prof Shane Higgins

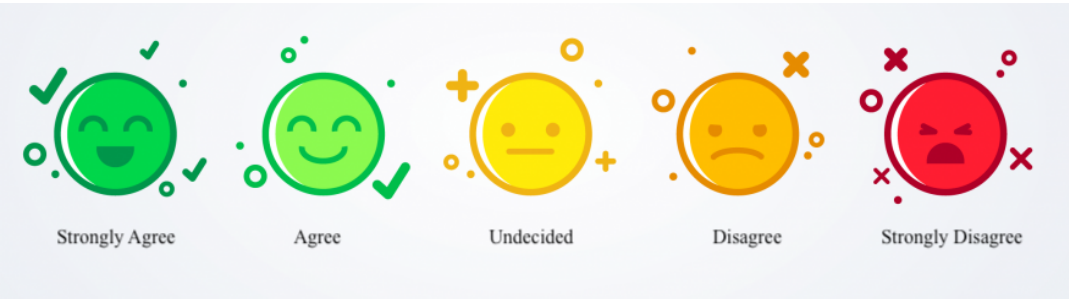
1. How does it make you feel visualising the 3D Baby with CDH?



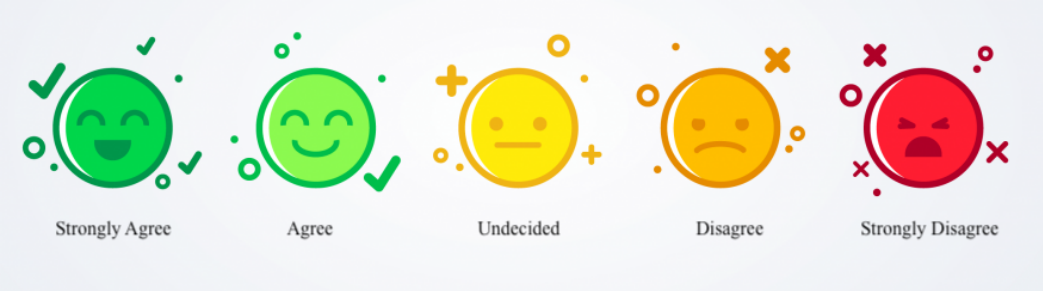
2. Over the past few weeks have you had the desire to read about or get information about the development of your baby



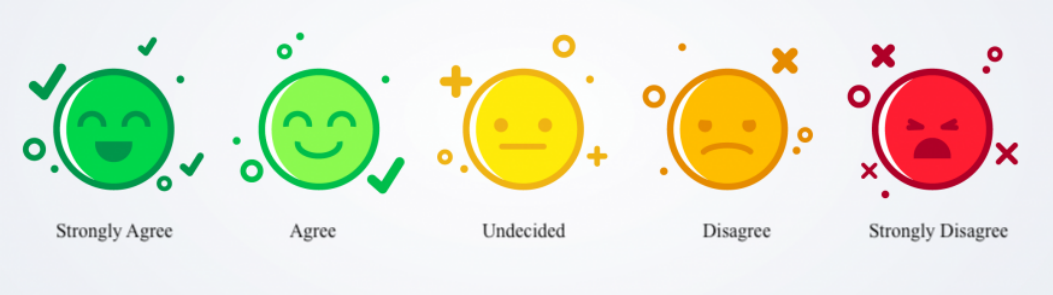
3. Does this learning experience help you to understand your baby's condition better?



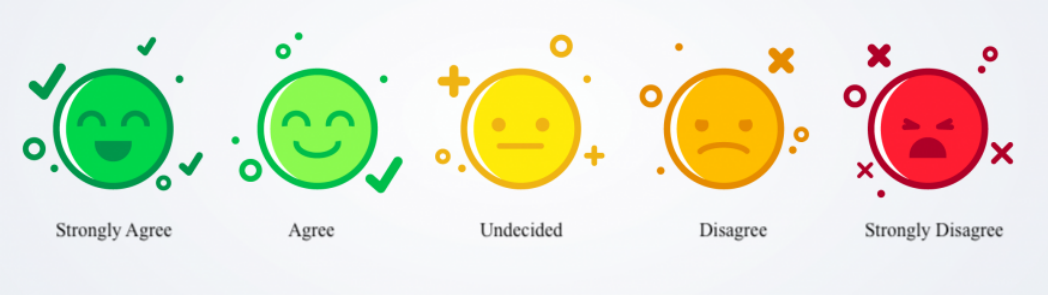
4. Will this VR experience help you to bond better with your baby?



5. Could you imagine what the baby's anatomy looks like after completing the VR learning experience?



6. Do you think tools like VR headsets could help parents that have had a prenatal diagnosis of a congenital abnormality?



Appendix 7: QR Codes

MCQ Code



Learning Experience Questionnaire



VR Design Questionnaire



Appendix 8: Ethics Forms and Responses

An tOspidéal Náisiúnta Máithreachais
The National Maternity Hospital
Founded in 1894

Sráid Holles, Baile Átha Cliath 2 • Holles Street, Dublin 2, D02 YH21
Telephone: (01) 6373100. Fax: (01) 6766623. Web: www.nmh.ie

Máistir/Master: Prof. Shane Higgins



PRIVATE AND CONFIDENTIAL

Dr. Grace Ryan
Academic Clinical Fellow
Obs & Gynae
National Maternity Hospital
Holles Street
Dublin 2

Thursday 19th September 2019

Re: Development of 3D images of pregnancy for use in Virtual and Augmented Reality
Our ref: EC23. 2019

Dear Fionnuala,

The above study was reviewed at the Research Ethics Committee meeting on Monday 16th September 2019. I am pleased to inform you that it has received approval.

One small point is that, the use of the hospital number does not come under the definition of anonymised data. Thus for confidentiality purposes the data should be encrypted.

Kind regards,

Yours sincerely,

[redacted]

Dr. John Murphy
Chairman,
Research Ethics Committee

C.c. Prof. Fionnuala Mc Auliffe, Consultant Obstetrician & Gynae, National Maternity Hospital

An tOspidéal Náisiúnta Máithreachais
The National Maternity Hospital
Founded in 1894

Sráid Holles, Baile Átha Cliath 2 • Holles Street, Dublin 2, D02 YH21
Telephone: (01) 6373100. Fax: (01) 6766623. Web: www.nmh.ie

Máistir/Master: Prof. Shane Higgins



PRIVATE AND CONFIDENTIAL

Dr. Grace Ryan
Academic Clinical Fellow
Obs & Gynae
National Maternity Hospital
Holles Street
Dublin 2

Tuesday 26th November 2019

Re: Development of 3D images of pregnancy for use in Virtual and Augmented Reality
Our ref: EC23. 2019

This amendment consisted of collecting Fetal MRI Scans. Your request was considered by the Research Ethics Committee on Monday 25th November 2019.

I am pleased to inform you that this has received ethical approval.

Kind regards,

Yours sincerely,

[redacted]

Dr. John Murphy
Chairman,
Research Ethics Committee

C.c. Prof. Fionnuala Mc Auliffe, Consultant Obstetrician & Gynae, National Maternity Hospital

UCD Connect

Grace Ryan <grace.ryan@ucd.ie>

LS-20-09-McAuliffe Am Req APPROVAL
5 messages

hrec@ucd.ie <hrec@ucd.ie> 7 July 2020 at 14:52
To: Grace Ryan <grace.ryan@ucd.ie>
Cc: Fionnuala McAuliffe <fionnuala.mcauliffe@ucd.ie>

Re: LS-20-09-McAuliffe: *To investigate the role of virtual, augmented and mixed reality in medical education*

Dear Grace,

Thank you for your request to amend (03/07/20) which has been **granted approval.** This is for the work and time period specified in your submission and is subject to the conditions below:

- Requests to amend and extend are limited to five requests within two years of the first approval date. The details of your approval to date are as follows:

  (Original Approval: granted 26/05/20)

  a. **Amendment: granted 07/07/20**

- This approval is granted on condition that you ensure that, in compliance with the Data Protection Acts 1988 and 2003, all data will be managed in accordance with your application and that you will confirm this in your End of Study Report (HR6);
- You may require copies of submitted documentation relating to this approved application and therefore we advise that you retain copies for your own records;
- Please note that the granting of this ethical approval is premised on the assumption that the research will be carried out within the limits of the law;
- Please also note that approved applications and any subsequent amendments are subject to a Research Ethics Compliance Review.

If you have any queries regarding the above please contact the Office of Research Ethics and please quote your reference in all correspondence.

Regards,

Tom

An tOspidéal Náisiúnta Máithreachais
The National Maternity Hospital
Founded in 1894

Sráid Holles, Baile Átha Cliath 2 • Holles Street, Dublin 2, D02 YH21
Telephone: (01) 6373100. Fax: (01) 6766623. Web: www.nmh.ie



Máistir/Master: Prof. Shane Higgins

PRIVATE AND CONFIDENTIAL

Dr. Grace Ryan
Registrar in Foetal Medicine
National Maternity Hospital
Holles Street
Dublin 2

Tuesday 11th February 2020

Re: To investigate the role of virtual and augmented reality in antenatal patient education
Our ref: (EC04.2020)

Dear Dr. Ryan,

The above study was considered by the Research Ethics Committee on Monday 10th February 2020. I am pleased to inform you that it has received ethical approval.

There are just a few points to note. Firstly, the Patient Information Leaflet should make it clear to the parents that the image they are being shown is not of their own baby but of an archived image.

The second point is in the Questionnaire, on question 6, the use of the term immersion was felt that many parents may not be sure what this term means and perhaps should be simplified for them.

The other point is that you should make it clear in your Patient Information Leaflet that you are going to review the patient's chart.

Kind regards,

Yours sincerely,

[redacted]

Chairman,
Research Ethics Committee

UCD Office of Research Ethics

Roebuck Castle
University College Dublin
Belfield, Dublin 4, Ireland

T +353 1 716 8767

An Oifig Eitic Thaighde UCD

Caisleán an Ruabhoic
An Coláiste Ollscoile, Baile Átha Cliath
Belfield, Baile Átha Cliath 4, Éire

hrec@ucd.ie
www.ucd.ie/researchethics

May 24th, 2020

Dr Grace Ryan
UCD School of Medicine
Belfield
Dublin 4

Re: LS-20-09-McAuliffe: *To investigate the role of virtual, augmented and mixed reality in medical education*

Dear Dr Ryan

Thank you for your response to the Human Research Ethics Committee – Sciences (21/05/20). The Decision of the Committee is that **approval is granted** for this application which is subject to the conditions set out below.

Please note that **public liability insurance for this study has been confirmed** in accordance with our guidelines.[i]

Please note that approval is for the work and the time period specified in the above protocol and is subject to the following:

- Any amendments or requests to extend the original approved study will need to be approved by the Committee. Therefore you will need to submit by email the *Request to Amend/Extend Form*;
- Any unexpected adverse events that occur during the conduct of your research should be notified to the Committee. Therefore you will need to Submit, by email, an *Unexpected Adverse Events Report*;
- You or your supervisor (if applicable) are required to submit a signed *End of Study Report Form* to the Committee upon the completion of your study;
- This approval is granted on condition that you ensure that, in compliance with the Data Protection Acts 1988 and 2003, all data will be managed in accordance with your application and that you will confirm this in your *End of Study Report*;
- Please note that further new submissions from you may not be reviewed until any **End of Study Reports due** have been submitted to the Office of Research Ethics. That is, any earlier study that you received ethical approval for from the UCD HRECs;
- You may require copies of submitted documentation relating to this approved application and therefore we advise that you retain copies for your own records;
- Please note that the granting of this ethical approval is premised on the assumption that the research will be carried out within the limits of the law;
- Please also note that approved applications and any subsequent amendments are subject to a Research Ethics Compliance Review.

.../.

The Committee wishes you well with your research and look forward to receiving your End of Study Report. All forms are available on the website www.ucd.ie/researchethics please ensure that you submit the latest version of the relevant form. If you have any queries regarding the above please contact the Office of Research Ethics and please quote your reference in all correspondence.

Yours sincerely

[redacted]
Dr Cliona McGovern
Chair, Human Research Ethics Committee - Sciences

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[i] http://www.ucd.ie/researchethics/information_for_researchers/insurance/

Appendix 9: Exploring the role of virtual reality in midwifery education: A prospective study

ISRCTN registry

ISRCTN12735607 https://doi.org/10.1186/ISRCTN12735607 [https://doi.org/10.1186/ISRCTN12735607]

Exploring the role of virtual reality in midwifery education: a prospective study

CrossMark [≠]

Condition category
Pregnancy and Childbirth
Date applied
30/11/2020
Date assigned
02/12/2020
Last edited
01/12/2020

Prospective/Retrospective
Retrospectively registered
Overall trial status
Ongoing
Recruitment status
Recruiting

Plain English Summary

Background and study aims
This research project is investigating the use of virtual reality and how these techniques may help to enhance learning in midwifery education. Research has shown that virtual reality can help with the learning process. Virtual reality enables the students to discover and explore their own knowledge, learn by doing, develop creativity, aid visual learners, and increase understanding of invisible concepts. This is unique to topics found within midwifery education. The main aim of this study is to find out whether virtual reality can provide an enhanced learning experience for students studying midwifery.

Who can participate?
Students studying midwifery in both the undergraduate and graduate entry programmes

What does the study involve?
Participation will involve a tutorial with a virtual reality headset, where the participant will undergo a lesson in 3D on the topic of fetal lie, position, and presentation of the fetus in pregnancy. It will be a learning experience that will last about 15 minutes. The researchers will provide instructions on the use of the VR headsets and a debriefing session will be held after the learning experience. The evaluation will consist of tests before and after the learning experience and a questionnaire to collect participants' opinions and attitudes on the use of this technology for learning purposes.

What are the possible benefits and risks of participating?
There is a learning opportunity for the participant to see fetal anatomy in 3D, topics pertaining to the third trimester of pregnancy and birth, complementing the teaching given in modules at University College Dublin. There are no known potential risks or harm involved with the study, but a potential risk to participants is cybersickness which can be defined as a range of clinical symptoms related to exposure to virtual reality. The researchers aim to minimise this risk by setting a limit of a maximum of 15 minutes when they are using virtual reality technology. If participants have any medical problems such as epilepsy, pre-existing binocular vision disturbances or psychiatric disorders, or suffer from a heart condition or other serious medical conditions, they will not be permitted to participate in the study as this is a safety precaution advised by the manufacturers.

Before taking part in the study each participant will be screened for any medical conditions as mentioned above, if a participant has any of the conditions mentioned above, they will not be permitted to participate in the study.

Where is the study run from?
University College Dublin (UCD) Perinatal Research Centre at the National Maternity Hospital (Ireland)

When is the study starting and how long is it expected to run from?
April 2020 to March 2021

Who is funding the study?
Investigator initiated and funded

Who is the main contact?
Prof. Fionnuala McAuliffe
fionnuala.mcauliffe@ucd.ie

Trial website

[]

Contact information

Type

Scientific

Primary contact

Prof Fionnuala McAuliffe

ORCID ID

https://orcid.org/0000-0002-3477-6494 [https://orcid.org/0000-0002-3477-6494]

Contact details

UCD Perinatal Research Centre
Obstetrics and Gynaecology
School of Medicine
University College Dublin
65/66 Lower Mount Street (3rd Floor)
Dublin
D2
Ireland
+353 (0)1 637 3126
fionnuala.mcauliffe@ucd.ie [mailto:fionnuala.mcauliffe@ucd.ie]

Additional identifiers

EudraCT number

Nil known

ClinicalTrials.gov number

Nil known

Protocol/serial number

Nil known

Study information

Scientific title

"VR Baby" in midwifery education: a prospective observational study

Acronym

Study hypothesis

The hypothesis of the proposed research study is that virtual reality can provide an enhanced learning experience and improve the understanding of invisible concepts. Midwifery education has a unique need for VR as an educational tool to enhance learning and understanding of the fetus during pregnancy and associated conditions.

Ethics approval

Approved 07/07/2020, Human Research Ethics Committee at University College Dublin (Office of Research Ethics, Roebuck Castle, Belfield, Dublin 4, Ireland; +353 (0)1 716 8767; hrec@ucd.ie), ref: LS-20-09-McAuliffe

Study design

Prospective observational study

Primary study design

Observational

Secondary study design

Cohort study

Trial setting

Other

Trial type

Other

Patient information sheet

Not available in web format, please use contact details to request a participant information sheet.

Condition

Effect of virtual reality in midwifery education

Intervention

Recruitment will take place via Brightspace, an eLearning University platform, and class announcements. Participants will be asked to provide written informed consent. The study is being carried out under the government-directed protocol and guidance in relation to COVID-19. The participants will undergo a lesson in a virtual reality learning environment on the topic of fetal lie, position, and presentation in pregnancy. Participants are given a short introduction on the use of the VR headset and controls. The participants then use the headset for 15 minutes. The participants' knowledge is assessed with a pre-test (MCQ1) and 2 post-test (MCQ2&3) 10-question MCQ. MCQ 1 will be taken immediately prior to the learning experience (control vs intervention), MCQ 2 will be taken immediately after the intervention and MCQ 3 will be taken 1 week later, after the intervention. This is followed by a questionnaire on the learning experience, which will assess attitudes and opinions on the VRLE and a questionnaire on the design of the virtual reality learning environment.

Intervention type

Device

Phase

Not Applicable

Drug names

Primary outcome measure

Knowledge measured by differences in MCQ scores pre and post test

Secondary outcome measures

1. Attitudes and opinions on the learning experience measured by a validated scale, the student satisfaction in learning and self-confidence scale, a 5-point Likert scale completed immediately after the learning experience
2. Attitudes and opinions on the design of the virtual reality learning environment measured by a validated scale, the simulation design scale adapted for the VRLE, a 5-point Likert scale completed immediately after the learning experience
3. Side effect profile to help assess the usability, measured using a questionnaire immediately after the learning experience

Overall trial start date

01/04/2020

Overall trial end date

31/03/2021

Reason abandoned (if study stopped)

Eligibility

Participant inclusion criteria

All students studying midwifery in both the undergraduate and graduate entry programmes at University College Dublin

Participant type

Healthy volunteer

Age group

Adult

Gender

Both

Target number of participants

40

Participant exclusion criteria

1. Non-English speaker
2. Aged under 18 years
3. Medical conditions: epilepsy, pre-existing binocular vision disturbances, psychiatric disorders, heart conditions, or other serious medical conditions

Recruitment start date

01/10/2020

Recruitment end date

31/03/2021

Locations

Countries of recruitment

Ireland

Trial participating centre

UCD Perinatal Research Centre
Obstetrics and Gynaecology School of Medicine University College Dublin 65/66 Lower Mount Street (3rd Floor)
Dublin
D2
Ireland

Sponsor information

Organisation

University College Dublin

Sponsor details

UCD Perinatal Research Centre
Obstetrics and Gynaecology
School of Medicine
65/66 Lower Mount Street (3rd Floor)
Dublin

D2
Ireland
+353 (0)1 637 3126
stephanie.begley@ucd.ie [mailto:stephanie.begley@ucd.ie]

Sponsor type

University/education

Website

https://www.ucd.ie/medicine/perinatal/ [https://www.ucd.ie/medicine/perinatal/]

Funders

Funder type

Other

Funder name

Investigator initiated and funded

Alternative name(s)

Funding Body Type

Funding Body Subtype

Location

Results and Publications

Publication and dissemination plan

Planned publication in a high-impact peer-reviewed journal.

IPD sharing statement:
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Intention to publish date

07/07/2021

Participant level data

Available on request

Basic results (scientific)

Publication list

Publication citations

Additional files

Editorial Notes

01/12/2020: Trial's existence confirmed by University College Dublin.

Appendix 10: "VR Baby", a virtual reality learning environment – does it help medical students to learn about complex topics in obstetrics and gynaecology?

ISRCTN registry

ISRCTN19845486 https://doi.org/10.1186/ISRCTN19845486 [https://doi.org/10.1186/ISRCTN19845486]

VR Baby, a virtual reality learning environment - does it help medical students to learn about complex topics in obstetrics and gynaecology?

CrossMark [#]

Condition category
Pregnancy and Childbirth
Date applied
30/11/2020
Date assigned
02/12/2020
Last edited
01/12/2020

Prospective/Retrospective
Retrospectively registered
Overall trial status
Ongoing
Recruitment status
No longer recruiting

Plain English Summary

Background and study aims
This study is investigating the use of virtual reality and how these techniques may help to enhance learning in medical education. Virtual reality (VR) can be defined as "real-time interactive graphics with 3D models". Research has shown that virtual reality can help with the learning process. Virtual reality enables the students to discover and explore their own knowledge, learn by doing, develop creativity, aid visual learners, and increase understanding of invisible concepts. This is unique to topics found within the obstetrics and gynaecology curriculum. The main aim of this study is to investigate the effectiveness of a virtual reality learning environment (VRLE) compared with a traditional tutorial learning environment amongst medical students.

Who can participate?
Students studying medicine, undergraduate or graduate entry level medicine programmes at University College Dublin (UCD)

What does the study involve?
Participants are randomly allocated to the intervention or control group. The intervention group will undertake a 15-minute lesson in a virtual reality learning environment (VRLE) that was created on the topic of stages of development in pregnancy. The VRLE is carried out under the government-directed protocol and guidance in relation to COVID-19. Participants are given a short introduction on the use of the VR headset and controls. The participants then use the headset for 15 minutes. The control group will undertake a traditional tutorial, which will take place online due to COVID-19 restrictions. The tutorial will involve a face-to-face teaching session using a PowerPoint presentation in small group settings. The evaluation will consist of a test before and after the intervention, along with a questionnaire on the learning experience and design of the virtual reality learning environment, as the researchers would like to hear about the opinions and attitudes on the use of this technology for learning purposes.

What are the possible benefits and risks of participating?

The benefit of the study is that there is a learning opportunity for the participant to see the stages of development in pregnancy in 3D, complementing the teaching given in modules at UCD. Participants' views and experiences are important to help the researchers develop new and innovative ways to provide medical education. There will be no impact on academic standing whether students choose to participate in the study or not. In terms of risks, there are no known potential risks or harm involved with the study, but a potential risk to participants is cybersickness which can be defined as a range of clinical symptoms related to exposure to virtual reality. This risk is minimised for the students by setting a time limit of a maximum of 15 minutes when they are using the virtual or augmented reality technology. If students have any medical problems such as epilepsy, pre-existing binocular vision disturbances or psychiatric disorders or suffer from a heart condition or other serious medical conditions, they will not be permitted to participate in the study as this is a safety precaution advised by the manufacturers. Before taking part in the study participants will be screened for any medical conditions mentioned above, and if participants have any of the conditions mentioned above they will not be permitted to participate in the study.

Where is the study run from?
UCD Perinatal Research Centre at the National Maternity Hospital (Ireland)

When is the study starting and how long is it expected to run from?
January 2020 to March 2021

Who is funding the study?
Investigator initiated and funded

Who is the main contact?
Prof. Fionnuala McAuliffe
fionnuala.mcauliffe@ucd.ie

Trial website

[]

Contact information

Type

Scientific

Primary contact

Prof Fionnuala McAuliffe

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Additional identifiers

EudraCT number

Nil known

ClinicalTrials.gov number

Nil known

Protocol/serial number

Nil known

Study information

Scientific title

"VR Baby", a virtual reality learning environment for medical students - does it enhance the understanding and learning of invisible concepts? A randomized control trial

Acronym

Study hypothesis

The educational landscape is becoming an increasingly dynamic environment in the 21st Century. Immersive technology enables the students to discover and explore their own knowledge, learn by doing, develop creativity, aid visual learners, and increase understanding of invisible concepts. It is hypothesized that immersive technology can enrich and enhance the learning experience, especially in relation to invisible concepts, which are unique to the curriculum in obstetrics and gynaecology. With this in mind, the aim is to investigate the use of virtual reality as an educational tool in obstetrics and gynaecology to teach medical students compared with a traditional face-to-face tutorial.

Ethics approval

Approved 26/5/2020, Human Research Ethics Committee at University College Dublin (Office of Research Ethics, Roebuck Castle, Belfield, Dublin 4, Ireland; +353 (0)1 716 8767; hrec@ucd.ie), ref: LS-20-09-McAuliffe

Study design

Single-centre randomized control trial

Primary study design

Interventional

Secondary study design

Randomised controlled trial

Trial setting

Other

Trial type

Other

Patient information sheet

Not available in web format, please use contact details to request a participant information sheet

Condition

Effect of virtual reality in medical education (obstetrics and gynaecology)

Intervention

Recruitment is to take place on Brightspace, an eLearning University platform and through class announcements. Students are invited to take part and asked to provide written informed consent. Participants are then randomly assigned to the intervention or control group. The intervention group will undertake a 15-minute lesson in a virtual reality learning environment (VRLE) that was created on the topic of stages of development in pregnancy. The VRLE is carried out under the government-directed protocol and guidance in relation to COVID-19. Participants are given a short introduction on the use of the VR headset and controls. The participants then use the headset for 15 minutes. The control group will undertake a traditional tutorial, which will take place online due to COVID-19 restrictions. The tutorial will involve a face-to-face teaching session using a PowerPoint presentation in small group settings. Participants knowledge is assessed with a pre-test (MCQ1), and 2 post-test (MCQ2&3) 10-question MCQ. MCQ 1 will be taken immediately prior to the learning experience (control vs intervention), MCQ 2 will be taken immediately after the intervention and MCQ 3 will be taken 1 week later, after the intervention. This is followed by a questionnaire (Likert-style scale) on the learning experience, which will assess attitudes and opinions on the VRLE and a questionnaire (Likert-style scale) on the design of the virtual reality learning environment.

Intervention type

Other

Phase

Drug names

Primary outcome measure

Knowledge measured by differences in MCQ scores pre and post test

Secondary outcome measures

1. Attitudes and opinions on the learning experience measured by a validated scale, the student satisfaction in learning and self-confidence scale, a 5-point Likert scale completed immediately after the learning experience
2. Attitudes and opinions on the design of the virtual reality learning environment measured by a validated scale, the simulation design scale adapted for the VRLE, a 5-point Likert scale completed immediately after the learning experience
3. Side effect profile to help assess the usability, measured using a questionnaire immediately after the learning experience

Overall trial start date

27/01/2020

Overall trial end date

31/03/2021

Reason abandoned (if study stopped)

Eligibility

Participant inclusion criteria

All students studying medicine, undergraduate or graduate entry level programmes at University College Dublin

Participant type

Healthy volunteer

Age group

Adult

Gender

Both

Target number of participants

40

Total final enrolment

56

Participant exclusion criteria

1. Non-English speaker
2. Aged under 18 years
3. Medical conditions: epilepsy, pre-existing binocular vision disturbances, psychiatric disorders, heart conditions, or other serious medical conditions

Recruitment start date

01/07/2020

Recruitment end date

31/10/2020

Locations

Countries of recruitment

Ireland

Trial participating centre

UCD Perinatal Research Centre
Obstetrics and Gynaecology School of Medicine University College Dublin 65/66 Lower Mount Street (3rd Floor)
Dublin

D2
Ireland

Sponsor information

Organisation

University College Dublin

Sponsor details

UCD Perinatal Research Centre
Obstetrics and Gynaecology
School of Medicine
65/66 Lower Mount Street (3rd Floor)
Dublin
D2
Ireland
+353 (0)866068822
stephanie.begley@ucd.ie [mailto:stephanie.begley@ucd.ie]

Sponsor type

University/education

Website

https://www.ucd.ie/medicine/perinatal/ [https://www.ucd.ie/medicine/perinatal/]

Funders

Funder type

Not defined

Funder name

Investigator initiated and funded

Alternative name(s)

Funding Body Type

Funding Body Subtype

Location

Results and Publications

Publication and dissemination plan

1. There is no study protocol available
2. Planned publication in a high-impact peer-reviewed journal

IPD sharing statement
The datasets generated during and/or analysed during the current study are/will be available upon request from Prof. Fionnuala McAuliffe (fionnuala.mcauliffe@ucd.ie).

Intention to publish date

01/07/2021

Participant level data

Available on request

Basic results (scientific)

Publication list

Publication citations

Additional files

Editorial Notes

01/12/2020: Trial's existence confirmed by Human Research Ethics Committee at University College Dublin.