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Declaration of Authorship

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Abstract

Medical education is a dynamic area that is always changing and evolving. Over the last decade, the use of computerized three-dimensional (3D) models in a virtual environment to enhance learning and teaching in anatomy education has become widespread. This research aims at investigating the effectiveness of using virtual reality in teaching the human cardiac anatomy in comparison with conventional or 2D digital teaching method. Also investigated was the degree of satisfaction associated with using immersive cardiac VR in learning. This research focuses on cardiac anatomy because it is one of the most challenging topics to teach and understand due to its complex three-dimensional nature. A randomized controlled study was conducted with 40 students, primarily graduate biomedical engineering students (20 in each group: control, non-VR and experimental, VR groups). Two learning methods were used to study the heart. The non-VR group used PowerPoint presentation whereas the VR group used immersive cardiac VR. Each student performed a pre- and post-intervention quiz on the same day. The students' anatomy knowledge and educational experience was evaluated. There was significant difference in anatomy knowledge within the 2 groups on pre- and post-intervention quiz .No significant difference was recorded between the 2 groups despite the fact that on average , post-intervention quiz scores in the experimental, VR group was 5% ($p = 0.12$) higher than in the non-VR group. The VR group found the learning experience to be significantly more engaging, enjoyable, and useful. In conclusion, immersive VR educational tools awarded a more positive learner experience. However, regarding which learning method is more effective in studying the heart, no significant differences were found in quiz scores between the 2 groups.

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Glossary

AR: Augmented Reality

CAVE: Cave Automatic Virtual Environment

CT: Computed Tomography

CVE: Collaborative Virtual Environment

FORs: Frames of Reference

SL: Second Life

HMD: Head-Mounted Display

Ghost: General Haptics Open Software Toolkit

VRTK: Virtual Reality Toolkit

MRI: Magnetic Resonance Imaging

PTSD: Post Traumatic Stress Disorder

RoSS: Robotic Surgical Simulator

SIM: Simulator

VE: Virtual Environment

VR: Virtual Reality

VW: Virtual World

WTK: WorldToolKit

1 Motivation

Virtual reality (VR) is gaining popularity in a number of fields in our society, from business to entertainment [1]. Notably, VR technology enables real-time exploration and manipulation of computer-generated real or artificial 3D multimedia environments [2]. It also has a lot of educational benefits because it helps you to visualize almost every object or go anywhere in a specific way [1]. This will entail the introduction of these technologies into educational settings, which will support a variety of learning styles while also simplifying teaching and learning processes [3]. The year 2016 was dubbed "the year of virtual reality" by the media, as the year when consumers' electronic gadgets, such as smartphones, will be able to bring virtual reality into their households [4]. The global virtual reality market size was valued at USD 15.81 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 18.0% from 2021 to 2028. The global virtual reality in education market size was USD 656.6 million in 2018 is projected to reach USD 13,098.2 million by 2026 while the Healthcare Market was valued at USD 2.14 Billion in 2019 and is projected to reach USD 33.72 Billion by 2027. VR in Healthcare Market by component comprise of Hardware, Software and Content [5] [6]. Developers have created fascinating experiences that allow users to go within the body's cells, explore the Solar System, and engage in recreations of historical wars. VR technologies were frequently employed for flight simulator training and exercises in particular [7]. On March 11 2020, the World Health Organization (WHO) declared the COVID-19 outbreak as a global Pandemic [8]. Subsequently, worldwide lockdown measures were declared, including the closure of schools and universities. As a result, education has changed substantially to e-learning which is challenging in medical education that often contains a considerable part of practical courses. Consequently, an online alternative to the practical part became necessary. However, VR enables students experience realistic situations that can motivate them to learn. It is simple to set up and use, with intuitive controls and software. Presently given the fact that every iPhone or Android smartphone can be used as a VR headset, one could argue that practically everyone now has their own VR device which can be used anywhere, other than the classroom [9] [10].

The health and medical education system has begun to incorporate more interactive media and online materials as new learning tools become available. The use of computer-based 3D models in anatomy education has become increasingly popular in recent years [11]. Anatomy, in particular, focuses on the detailed structure of the different systems of the human body, and a variety of descriptive models to provide an in-depth understanding have been used to facilitate this. This visual science is considered a crucial foundation for medical education as this is important for the accurate diagnosis in organs and human systems [12]. Learners identify structures and their spatial relationships when learning anatomy. Despite this, medical students frequently struggle to grasp three-dimensional (3D) anatomy from visual images in textbooks and PowerPoint presentations [13] [14]. The traditional medical education are associated with several problems as they provide a limited spatial understanding obtained from didactic lectures and restricted anatomic dissection [15]. Also, traditional modalities' (textbooks and 2-Dimensional (2D) images) grasp of spatial relationship is unclear; it needs expertise to explain, and lacks sufficient depth to demonstrate a specific teaching point. Furthermore, the human cadaver which is one of the teaching anatomy methods is associated with several limitations, for instance, the rising expenses, decreasing availability, and the decay in quality [16] [17]. These issues are overcome by 3D modelling which enables visualization of the spatial relationships between structures from various viewpoints, is reusable, is of changeable size, and allows explorative details which improve understanding [15]. Hence, it has become critical to develop modern methodologies that focus on both efficient and high-quality anatomy education and learning. In light of recent technological advancements in the field of VR, VR has proved itself to be a valuable tool for training in all areas of health sciences, particularly anatomy in medical education [18]. Also, anatomy teaching is also seen to be necessary for graduate students enrolling in a biomedical engineering program. This appeared to be especially important for students interested in and using medical images. These students typically have backgrounds in electronics, instrumentation, and no strong background in biology. Hence, it became clear that these students are deficient in anatomy knowledge and would benefit from a better understanding of human anatomy, particularly the region of the body that was involved in this research; the heart. Through head-mounted display devices, virtual immersion is achieved and the user can manipulate and interact with virtual objects, move about in the virtual world, interact with other users verbally and non-verbally, create and play, and so on [10]. This is particularly fascinating because its application allows effective studying of the interior of the human heart [1].

Therefore, this thesis aims at investigating the effectiveness of using virtual reality in teaching human cardiac anatomy in comparison with conventional or 2D digital teaching method. Also to be evaluated is the degree of satisfaction in using VR to study the heart. Students' performance on the quiz to assess their heart anatomy knowledge prior and after teaching will be noted as the primary outcome and the secondary outcome noted will be learner's experience in using VR to study the heart.

1.1 Structure of Thesis

The rest of the thesis work is structured as follows; chapter 2 provides definitions and overview of the virtual technologies and VR systems. Some applications and challenges of VR are also presented here. Chapter 3 provides an overview of education with and without VR technology as well as anatomy in medical education. Chapter 4 presents the literature research on the topic been done. Previous and current state of art case studies of VR in education, medical education as well related work in its application to specific anatomic regions for example the heart is discussed here. Chapter 5 dives into the methodology incorporated into achieving the goals of this research. Chapter 6 of the thesis presents the results of the experiments conducted. Chapter 7 comprises of the discussion of the thesis results and finally chapter 8 presents the conclusion and future works of this thesis.

2 Virtual Reality

This chapter gives an overview of virtual technologies, particularly in virtual reality. It begins with basic definitions of some important terminologies that are relevant in virtual technologies such as AR, VR, MR, the 3 I's, amongst others. The chapter also gives a comprehensive overview of VR systems: Input devices, output devices and software. The 3D interaction possibilities in VR are also mentioned in this chapter. Some challenges in VR technologies end the chapter.

2.1 Definitions

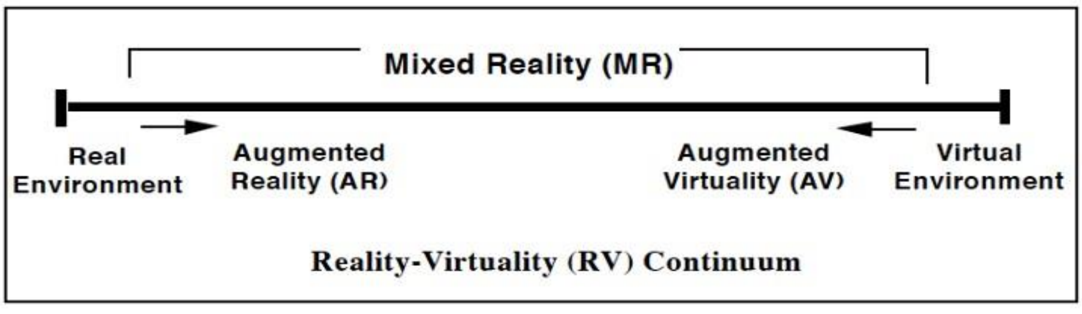

Figure 1 : Milgram's Reality-Virtuality Diagram [19]

The Milgram's reality-virtuality diagram, as shown in Figure 1, is a continuous scale ranging between the complete virtual, a virtuality and the complete real, reality. It therefore encompasses all possible variation and compositions of real and virtual objects. The concept was first introduced by Paul Milgram. The area between the two extremes, where both the real and the virtual are mixed, is called mixed reality. This in turn is said to consist of both augmented reality, where the virtual augments the real, and augmented virtuality, where the real augments the virtual [20].

Virtual Reality (VR) fully consists of a computer-generated virtual world that immerses the user in the experience. It not only places a user inside a computer-generated environment in real time – it is able to completely immerse a user in a virtual world, removing any restrictions on what a user can do or experience. This paradigm is becoming increasingly common, due to the fact that computer graphics have advanced to a point where the images are often indistinguishable from the real world [21] [22].

Augmented Reality (AR) 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, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory, among others. This technology overlays and integrates computer-generated content (3D designed object; videos, audios, graphics, or images) into the real-world environment. It is true, virtual and real-world co-exists perfectly in an AR world [23] [24].

Mixed Reality (MR) is merging of the real and virtual worlds to produce altogether new environments and visualizations, where physical and digital objects co-exist and interact in real time. MR does not exclusively only take place in either physical or virtual world but, it is hybrid of reality and virtual reality, which includes both AR and VR via immersive technology. The origins of the term MR can be tracked back to a 1994 research study by Paul Milgram and Fumio Kishino [19]. The term "Mixed Reality" was first used in the context of computer interfaces in this academic research (Figure 1). Milgram and Kishino defined the MR as "a particular subclass of VR related technologies that involve the merging of real and virtual worlds". The paper stated that MR involves the blending of real and virtual worlds somewhere along the "real-virtuality continuum" which connects completely real environments to completely virtual ones. As shown in the Figure 1, the RV continuum ranges from completely real to completely virtual environments (VE) and encompasses AR and Augmented Virtuality (AV). MR covers the portion of the continuum between the completely real environment, and completely virtual environment. However it always involves merging elements of the real and virtual world, and so the ends points of the continuum are not considered Mixed Reality [25].

Other key terminologies are:

Ralph Schroeder defined *virtual environments* and *virtual reality* technology as “a computer-generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in and to interact with that environment”. *Virtual worlds (VW)* are persistent virtual environments in which people experience others as being there with them - and where they can interact with them. The difference between virtual reality or virtual environments as against virtual worlds is that the latter term has been applied to persistent online social spaces; that is, virtual environments that people experience as on-going over time and that have large populations which they experience together with others as a world for social interaction [26].

Presence is defined as the “state of being mentally immersed ”, “sense of being there” or as the “feeling of being in a world that exists outside of the self” [27].

Cyberspace is a location that exists only in the minds of the participants, often as a result of technology that enables geographically distant people to interactively communicate [28].

Telepresence is the ability to directly interact (often via computer mediation) with a physically real, remote environment from the first-person point of view; there are no restrictions on the location of the remote environment, and there are no restrictions on the size of the device used to carry out the user's commands at the remote location [28].

Summary of similarities and differences between VR, AR, Telepresence and Cyberspace [28]

AR and telepresence can be considered close relatives of VR. AR mixes the physical world with computer generated information. The user is able to interact and affect the remote environment by their actions. In terms of physical reality, AR is here (proximal) and telepresence reality is there (distal). Telepresence differs from the general case of VR by taking input from the physical world as opposed to one that is entirely computer generated.

The relationship between cyberspace and VR is more complicated because their features seem to intersect with each other. The major difference is that cyberspace does not imply a direct sensory substitution for the user. Interaction in VR is not necessarily among multiple people, but rather between a person and a virtual world (which may not include other people). Both are examples of interactions with a virtual world or community mediated by technology. Cyberspace implies mental immersion with other humans. VR implies sensory immersion within a computer mediated virtual world. Cyberspace is not a medium per se but a feature of many different media.

2.1.1 Overview of VR

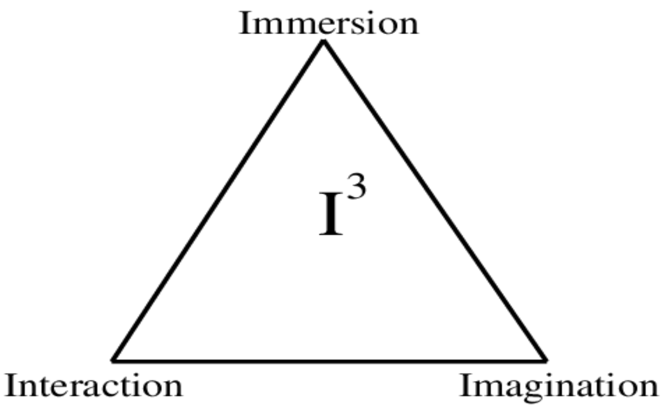

Figure 2 :Virtual Reality Triangle : The Three I's [29]

Figure 2 shows the characteristics of VR, the three 'I's: immersion, interaction and imagination [29].

First, the *immersion* aspect of VR is the characteristic that makes the virtuality real and makes a user feel immersed in a virtual environment and be completely separated from the real world. Until now, visual features incorporated utilizing 3D computer graphics have been the primary tools used to isolate the user's visual senses. As a result, the quality of display devices and rendering software has a significant impact on immersion. However, as the technology for simulating human five senses (i.e., hearing, seeing, feeling, smelling, tasting) improves, users will soon be able to see, hear, and feel objects but also smell or taste them.

Second, the *interaction* characteristic is usually thought of as a dynamic aspect that allows the user to interact with virtual objects in addition to seeing, hearing, and feeling them. The user can change the state of a virtual environment, as well as the objects in it, by interacting with them as with other people in real time. As a result, he becomes more immersed in the virtual world.

How a virtual world, with all the objects and people in it, behaves and works depends on the *imagination* characteristic [29]. The extent to which an application is able to solve a problem, thus, the extent to which a simulation performs well depends very much of this aspect. It also refers to the mind's capacity to perceive non-existent things [30].

Again according to a book written by William Sherman and Alan B. Craig , the four key elements of VR experience are: a virtual world, immersion, sensory feedback, and interactivity [28]. A virtual world is an imaginary space often manifested through a given medium. It refers to a description of a collection of objects in a space and rules and relationships governing these objects. In VR systems, such virtual worlds are generated by a computer. Immersion, mental and/or physical, is the sensation of being present in an environment, rather than just observing an environment from the outside. Sensory feedback is the selective provision of sensory data about the environment based on user input. The actions and position of the user provide a perspective on reality and determine what sensory feedback is given. Interactivity, finally, is the responsiveness of the virtual world to user actions. Interactivity includes the ability to navigate virtual worlds and to interact with objects, characters, and places.

The inhabitants of virtual environments can be classified as bots and avatars. A bot is an autonomous agent that pursues its own goals. On the contrary, an avatar — a representation of a human being — is under the direct control of that human being. VR enables people and their avatars to demonstrate two classes of behaviours: independent behaviours, such as waving a hand, are performed by the avatar alone; they can depend on other object in the environment and Interactive behaviours, like picking up a pen or shaking hands, require that the avatar locates other objects, possibly objects moving unpredictably in the environment, and moves in relation to those objects [33] [34].

2.2 Applications of VR

Military: VR has been adopted in all three major branches (army, navy, and air force), where it is used for virtual training (immersive and situation awareness), simulation (flight, vehicle and battlefield), virtual weapon manufacturing and medical therapy for veterans amongst others. The main benefits in military are time and cost effectiveness; realistic scenarios can be recreated with 100% control as well as achieving higher and better level of engagement and understanding. Also it is measurable because immediate feedback from participants can be obtained to help coordinate further training. For example, Australia is funding Defence Science Technology Group that develops VR training program for the military to prepare soldiers for all situations that might wait for them [31] [32].

Education: Education has moved on from books, pencils and pens to the use of interactive digital technologies to help impart knowledge and understanding. VR is used in these situations for teaching and learning. The benefit of this is that, it helps large groups of students to interact within a three-dimensional environment as well as with each other. It is capable of presenting complicated data to students in an accessible manner, which is both enjoyable and easy to understand. Plus, in order to learn more about them, these students may interact with the objects in that environment. For example, astronomy students explore the solar system with VR as with anatomy students learning about the human body [33]. Other use cases of VR in education include virtual field trips; for example, free downloadable Google expedition app used with an inexpensive cardboard headset incorporated with a smartphone enables students experience European castles, Asian temple, language immersion; for example, Unimersiv, an app that works with the Oculus Rift headset, allows users to practice their language skills with people from all over the world and philosophy; for example, the Sevenoaks School in the United Kingdom utilized VR headsets to educate and introduce philosophy students to Rene Descartes' dream argument in his Meditations on First Philosophy [34].

Entertainment: The entertainment industry is one of the most enthusiastic advocates of VR, most notable in video games and virtual worlds. But other areas that are equally common include: virtual museums, e.g. interactive exhibitions, galleries, theatre, e.g. interactive performances, virtual theme parks, discovery centres. Many of these areas fall into the category ‘edutainment’ in which the aim is to educate as well as entertain [35]. Music VR experience is gradually becoming a game changer in the industry [36].

Engineering: This includes the use of 3D modelling tools and visualisation techniques as part of the design process. VR helps engineers to display their project in 3D and gain a better understanding of how it works. In addition, they can detect any flaws or potential risks before implementation. For example, state of the art VR with advanced tracking and projection facilities to help design the next generation of Land Rovers can be seen at the JLR Virtual Reality Centre in the UK. Also, Balfour Beatty Rail, a rail infrastructure contractor, includes VR for planning, prototyping and construction purposes, and helps with project realisation [37]. VR engineering solutions are also applied in aircraft and appliance manufacturing [38].

Healthcare: This industry is one of the biggest adopters of VR and one of the benefits of this technology is that it helps healthcare professionals to learn new skills as well as refreshing existing ones in a safe environment. Plus, it facilitates this without causing any danger to the patients [39]. Application of VR in healthcare can be divided into 4 main areas [40] :

1. Communication interface: presence and avatar.
    - Presence: Virtual world (VW), virtual environment (VE) and VR provide the remote patient with a sense of embodiment that has the potential to facilitate the clinical communication process and positively affect group cohesiveness in group- based therapies. Also Collaborative virtual environments(CVE) allow multiple simultaneous users, in particular the patient and the therapist, who can communicate with each other through their avatars [41] [42].
    - Avatar: The CompBioMed Centre of Excellence, an international consortium of universities and industries, is developing a program that uses a supercomputer-generated simulation of an individual's physical and biomedical information for clinical diagnostics to create a hyper-personalized avatar or "virtual human". This allows clinicians to do more precise diagnoses, develop healthcare interventions based on a patient's specific physiology, and conduct personalized medicine and clinical simulations for optimal treatment [43].
2. Medical education and training: VWs provide unique opportunities in clinical teaching and interventions. Clinicians and students can understand significant physiological concepts or fundamental anatomy by 3D visualization of large volumes of information and databases [44]. VWs such as Second Life are increasingly used as mediums for public health education: provide healthcare information, educate and improve patients’ healthcare knowledge. For example, the University of Plymouth successfully evaluated a sexual health project in Second Life, designed to provide education about sexually transmitted infections, prevention of unintended pregnancy and

promotion of equalitarian sexual relationships [45]. Second Life has been used for disaster simulation and nursing training [46].

3. Surgical simulation and planning – In neurosurgery, laparoscopic & endoscopic, simulators and other (radiology, orthopaedic): Complex operative procedures can be taught with VR – the results of clinical investigations can already be used (for example CT, MRI scans) to construct all or part of a patient's accurate VR model [47]. Supercomputers today allow the incorporation of very large databases derived from structural imaging and simultaneous functional mapping of diseased organs that can be used to give the surgeon the ability to rehearse in VR a potentially complicated surgical procedure before attempting to do so with a patient [48].
4. Therapy - Phobias, Post-Traumatic Stress Disorder (PTSD), Anxiety Disorders, Rehabilitation, and Clinical & Pain Management: In the psychotherapeutic field, VR can also be described as an advanced imaginary system: an experiential form of imagery that is as effective as reality in inducing emotional responses [49] [50]. The feeling of "presence" that patients experience in these environments, involving all the sensory motor channels, enables them to really "live" the experience in a more vivid and realistic manner than they could do through their own imagination [51]. This implies fewer therapy sessions, and, thus, lower treatment costs [52]. Complete VR systems for the treatment of common anxiety disorders and specific phobias, such as: fear of heights, fear of flying, driving phobias, social phobia, fear of public speaking, fear of spiders, panic disorder and PTSD have been developed by numerous companies since 1990 [48].

Other areas VR is applied in include scientific visualisation, media, business, telecommunications fashion, heritage, sport, and programming languages [53].

2.3 VR System

The VR system enables exchange of information in a virtual environment. Information is exchanged through the interface to the virtual world. The user interface is the gateway between the user and the virtual environment [54]. The first commercial version of a VR system was developed by Morton Heilig in 1956 [55].

2.3.1 Components of VR System

Typically, a VR system is composed of [30] [56]:

- A database construction and virtual object modelling software
- An input tool (trackers, gloves or user interface)
- A graphic rendering system
- An output tool (visual, aural and haptic)
- A VR sensory stimuli delivery: using various forms of visual display technology that integrate real-time computer graphics and/or photographic images/video with a variety of other sensory (audio, force-feedback haptic/touch sensations and even olfactory) output devices. Other methods employ 3D displays that project on a single wall or on a multiple wall space (multi- wall projection rooms are known as CAVES) [57]. Other gadgets are: a helmet or head-mounted display in high-resolution, 3D sights and sounds, head and/or limb-tracking hardware, and specialized software to reproduce an interactive virtual environment [48].

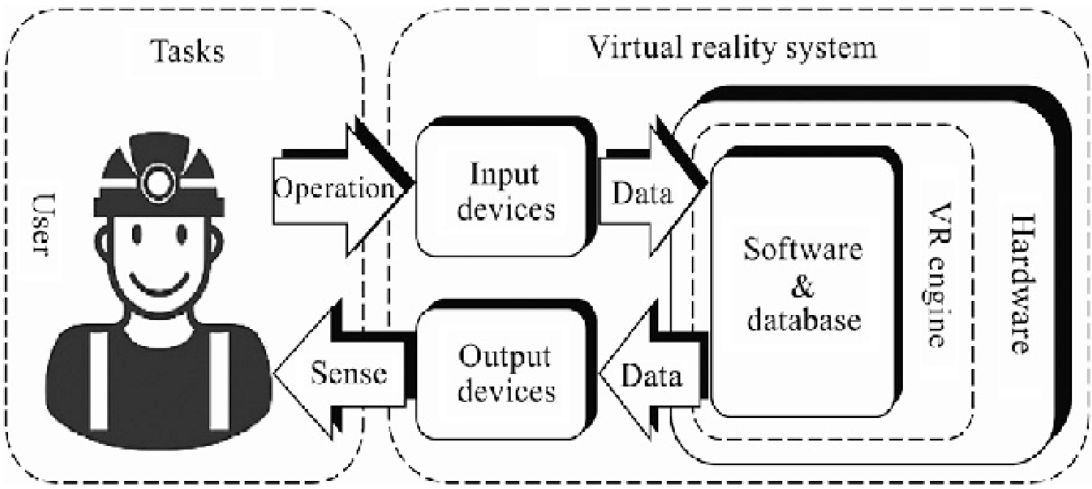

Figure 3: Components of VR system [58]

2.4 Input Devices

Without input, a computer-generated environment cannot be interactive, much less be considered a VR system. They primarily comprise of body trackers, referring to how the computer sees the user, voice or sound recognition, referring to how the computer hears the user and physical controllers referring to how the computer feels the user [59].

2.4.1 Trackers: Three-Dimensional (3D) Position Trackers

Position tracking refers to the computerised sensing of the position (location and /or orientation) of an object in the physical world whiles a position sensor is the device that reports its location and/or orientation to the computer. Position tracking uses a combination of hardware and software to achieve the detection of its absolute position through calculation [28]. However, a position, often known as a point, is a single location in two-dimensional (x, y axes) or three-dimensional (x, y, z axes) space that may or may not be occupied by a physical object. Positions exist before we measure or describe them in any way, but we need to provide coordinates for positions in order to make calculations [60]. Positional tracking is an essential technology for virtual reality (VR) making it possible to track movement with six degrees of freedom (DOF). DOF refers to the movement of a rigid body inside space [61]. When it comes to VR, DOF are used to describe axes that are tracked. Tracking comes from the ability to monitor a change of angle or distance on the axes by using hardware. 3 DoF simply means orientation tracking: the 3 axes which an object can be rotated about are tracked. 6 DoF VR headsets allows for the position of the headset to be tracked, as well as the orientation of the headset [62]. There are 6 DOF which are divided into two categories, rotational movements (which define orientation): pitch, yaw and roll and translational movements (which define location along the x, y, and z axes): left/right, forward/backward and up/down. Thus, 3 types of translation + 3 types of rotation = 6 DOF [61].

Several tracking methods, each with its own benefits and limitations, found in current VR system are optical, inertial, electromagnetic, mechanical, ultrasonic and neural trackers [28]. All 3D trackers, regardless of the technology they use , have a few key performance parameters in common, such as accuracy, jitter, drift , and latency [30]. The body parts and techniques of body tracking commonly used in VR applications include tracking the head, hand and fingers, eyes, torso, feet, other body parts and indirect tracking [28].

Optical trackers: Optical tracking systems monitor the user's position through the use of visual information [63]. Optical tracking identifies the pose of a tracked object by measuring light that is either transmitted or reflected by this object. When this light is transmitted from the object—typically through LEDs—we refer to this as active optical tracking. In passive optical tracking light is reflected [64]. The most common for VR systems is to use one or more fixed video cameras that act as electronic eyes to surveille the tracked object or person. This is referred to as the outside –in tracking. Frequently, a suite of video cameras are used, each in a fixed location. Computer vision techniques are then used to determine the object's position based on what the cameras "see" [18].

The opposite case is referred to as "videometric tracking or inside-out tracking"—where the camera is located on the participant and looks out at the world. This implies that the camera is attached to the object being tracked and watches the surroundings, rather than being mounted in a fixed location watching the tracked object. For this system to work, distinct landmarks at known locations must be placed. These landmarks act as known reference points in the world [28] [30].

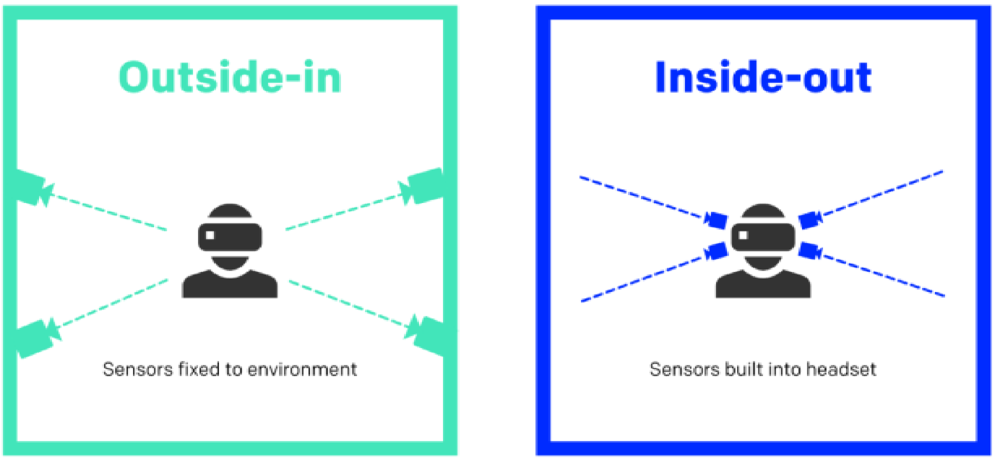

Figure 4 : Outside-in and Inside-out Optical Tracking [65]

Electromagnetic tracking: These systems are popular input devices for VR systems because they do not require line of sight to the tracked object. This method uses a transmitter to generate a low-level magnetic field from three orthogonal coils within the unit. However, because they use an electrically generated and received magnetic field to determine the six degrees-of-freedom of the sensor device, metals interfere with the functionality of such a system. One major advantage is that these systems have no line of sight restriction. The absence of this restriction allows the users to move about in a space that might have multiple visual or sound obstacles between them and the transmitter [59] [63].

Mechanical tracking: This operates by attaching linkages to the object you wish to track. Those linkages have sensors at each of the joints that report the angle between the linkages. Often this is done by placing a variable resistor (potentiometer) at the joint and reading the voltage there. As the angle of the linkage changes, the amount of resistance in the potentiometer changes and a corresponding change in voltage (that you can measure) occurs. The voltage can then be used to determine the angle between linkages. This information, in combination with the angles between all other linkages in the system, can be used to compute the location and pose of the object [66].

2.4.2 Speech Recognition (Audio Input)

As speech recognition systems grow more common, they offer a great way for people to communicate naturally with computers**.** This is especially true with VR applications, where the goal is to provide the most natural form of interface possible. The ideal speech recognition system would be able to recognize context and use it to interpret speech, as well as being able to process a steady stream of speech in any speaker. These systems generally map audio sounds to text strings. These strings are then matched with a set of pre-programmed possible responses. Three control methods of activating selective listening by the voice recognition system include push to talk , name to talk and look to talk [28].

2.4.3 Physical Controllers

This describes how the computer feels the user. They are direct physical inputs into the systems. These may include buttons, switches, valuators that are generally mounted on a "prop" or a "platform". Some examples are HTC Vive Controllers, Oculus touch [67].

Figure 5 : HTC Vive and Oculus Controllers [68]

Other input devices include wand or joystick, keyboard, 3D mouse, pinch gloves, data gloves,3D mice and bats, Dexterous manipulators, spaceball, cyberman [69] [70]**.**

2.5 Output Devices

An important aspect of a VR experience is how the user perceives the environment. Their physical perception of the virtual world is entirely dependent on what the computer displays. At least five senses provide information to the brain in the human perceptual system. Three of these senses – visual, aural, and haptic – are commonly presented with synthetic stimuli in a VR experience [63]. There are three basic arrangements for all sensory displays:

Stationary displays (like rear projection screens and audio speakers) are fixed in a place. The output is rendered to reflect the changing position of user's input sensory organs. Example: Desktop/Monitor based VR, Projection VR: CAVE, Powerwall [71].

Head based displays are worn on or attached to the user's head and move along with the head. Here the display move and remain in a fixed position relative to body's sensory inputs. Example: Occlusive HMDs, Noninclusive HMDs [71].

Hand based display move in conjunction with the user's hand. All senses cannot receive stimuli from all type of displays. Example : Palm VR [71].

2.5.1 Visual Displays

All of our senses give us vital information about our surroundings, but the one we rely on most is vision [72]. In VR, the visual displays describe how the user sees the virtual world. The visual display portion of a VR display generally has the most influence on the overall design of the VR system. This influence is due to the visual system being the predominate means of communication for most people. Each type of visual display paradigm (stationary, head-based, and hand-based) has its own specific benefits and disadvantages, which are further influenced by advances in technology, and the amount of monetary resources available. In addition to these basic paradigms, all the visual displays can either display stereoscopic images, or monoscopic images [59].

DLP (digital light Processing) projector, LCD (liquid crystal display), and LcoS (liquid crystal on Silicon) are the latest display technologies which are customized for VR. Example : Google Glass, Microsoft Hololens, and Avegant Glyph [71].

2.5.1.1 Head-Mounted Display (HMDs)

They refer to visual output devices that project virtual images directly right in front of the user's eyes. They are worn directly on the head and, due to their physical proximity, can cover the entire field of vision of the user. Due to the correspondence of the projections and the head movements, the entire environment can be viewed up to 210° field of view, courtesy of StarVR headsets [73] [74].

A unit consists of a helmet and small CRTs or liquid-crystal displays (LCDs) in a pair of goggles. The field vision on the display screens are expanded by the optical system producing an imaginary screen that appears to be positioned several meters in front of the viewer. Some types are mounted on the face in the form of glasses. Development and improvement of the technical aspects of these systems have been recently carried out. HMDs have the following features: (1)large, wide ranging screens are possible for vision, (2) miniaturization and weight reduction are possible for usability, (3) it is possible to superimpose the image on an external scene by means of see-through function [75]. Figure 6, shows few of the popular head mounted displays used for virtual technologies.

Figure 6 : Popular Models of Head Mounted Displays [3]

2.5.1.2 Stationary Displays

Most of the VR headsets are fully immersive, which means that they are generating a three-dimensional experience that appears to surround the user. These displays are usually combined with sensors which make the experience more immersive. Many of the sensors on the headset are essentially tracking position and orientation [76]. Some examples of these displays include:

1. Cave automatic virtual environment (CAVE): The walk-in VR room for complete immersion in the virtual environment [77]. A CAVE is an immersive virtual reality environment where projectors are directed at three to six walls of a cube-shaped room. The floors, walls and ceilings are the projection screens [78]. The CAVE allows one or more users to become fully immersed in and interact with their virtual models. CAVEs reduce prototyping costs, speed time to market, enable research, and lead to more confident decisions [79]. Diverse applications range from medical fields, interior design in automobile construction to building and landscape architecture to the realistic assessment of any interior [77].

2. Domes: The VR solution for particularly distortion-free 3D images in almost any size [80].VR domes are made using small screens capable of projecting high-resolution images emulating entire scenarios or environments [81]. They assume the shape of a dome and often provide considerable precision in graphics along with room for multiple users, and a huge advantage is that the user is able to freely move around anywhere without much restriction [82]. It is commonly used for presentation. Other application areas include projecting the virtual appearance of the universe, flight and driving simulation, entertainment industry, art galleries and screening other content according to the preference of the target audience [81].

3. Powerwalls: The VR wall for transition-free images with multiple projectors or single projector [83]. It is a large, ultra-high-resolution display that is constructed of a matrix of other displays, which may be either monitors or projectors. It is important to differentiate between Powerwalls and displays that are just large, for example, the single projector display used in many lecture theatres. These displays rarely have a resolution higher than 1920x1080 pixels and so present the same amount of information as on a standard desktop display. With Powerwall displays, users can view the display from a distance and see an overview of the data (context), but can also move to within arm's length and see data in great detail (focus) [84]. This technique of moving around the display is known as physical navigation and can help users to better understand their data [85].

2.5.2 Sound Displays

Sound displays are computer interfaces that provide synthetic sound feedback to users interacting with the virtual world. The sound can be monaural (both ears hear the same sound) or binaural (each ear hears a different sound) and can be generated as mono, stereo or 3D audio [30] [86].Virtual sound is computed by 3D sound generators and they can be used to present quantitative as well as qualitative information. It can be presented either as unembodied (as part of the background) or as the voice agents (characters in the world). Sound can be used to direct the attention of the participant and this greatly enhances the participant's ability to become mentally immersed in the virtual world via head-mounted displays (HMDs) and headphones [28] [87]. Latest speaker technology includes bone conduction methods which vibrate the skull and propagate the waves to the inner ear. Example : Google Glass [71].

2.5.3 Haptic Display

Haptic displays relate to the sense of touch thus how the user feels the display. These devices range from small units that sit on the desktop or are worn on the hand to large robotic devices capable of lifting a man off the ground. Some of what is called "haptic display" is related to the muscular and skeletal systems. Therefore, haptic displays are usually divided into two categories: "tactile" (input through the skin), and "proprioceptic" (input through the muscular and skeletal systems). Tactile sensations are useful for applications in which the user must piece together small objects or work with instruments that require very sensitive, precise adjustments, such as a surgeon might require. Because there are so many different aspects to haptic feedback (taction, proprioception, thermo-reception, electroreception, etc.) and so many different body parts that the display can be coupled with, haptic displays have a very wide range of logistic qualities. Compared with visual and aural devices, haptic devices tend to be more specifically tied to particular applications. Some of the logistic qualities include user mobility, interface with tracking methods, environment requirements, associability with other sense displays, portability, throughput, encumbrance, safety and cost [88] [28] [63].

In summary, VR systems make use of (in decreasing prevalence) visual, aural, and haptic displays. Use of other sensory displays has also been done. Of these the vestibular sense (the sense of balance) is the most common. In fact, it has been a very common form of display for flight simulation for decades. Olfactory display (smell) has been experimented sparingly, and computer-controlled display of gustation (taste) is virtually non-existent [59].

2.6 VR Software and Programming

Software systems used to convey the description of the virtual world to the VR hardware often make use of a variety of application libraries and toolkits to create, render, and allow interfacing to the virtual world. These systems can be classified into four groups: world creation, hardware interface, rendering, and application development tools. A graphics library is a collection of software routines that enable a programmer to execute fairly complex actions by making relatively simple subroutine and function calls whiles Toolkit is an extendable library of object oriented functions designed for VR specifications Some examples include WorldToolKit, Java 3D, General Haptics Open Software toolkit GHOST, OpenGL, Silicon Graphics' (Open) Performer library, Minimal Reality Toolkit, CAVE library, Virtual Reality Toolkit (VRTK) [28].

Even though good computer programming skills are still sometimes required for VR experiences, there are software packages designed to ease the burden of writing VR applications. Some commercial vendors provide predesigned VR applications for areas such as scientific visualization. Now design teams spend nearly little time on these concepts and instead can concentrate nearly 100% of their effort on the following issues: Story development (storyboarding); Representational mapping and aesthetics (what to render rather than how to render); Constructing the virtual world; Landmarks and other way finding aids; Interactivity between the user and the virtual world; Effective and entertaining presentation methods; and Problem solving and creativity (meeting the needs of the user). Likewise, teams can now be more integrally woven around scientists, artists, doctors, teachers, students, homemakers, and writers. That is, VR applications should be designed by and for the people who will use the end result [63] [30]. However, there are a number of pre-designed medical VR apps on a variety of platforms including Android, Daydream View, Samsung Gear VR, iOS, HTC Vive, PlayStation VR and Oculus Rift that require no computer programming skills to use [89]. In this research thesis, one of these predesigned medical apps from Steam was implemented.

2.7 Interaction Possibilities

2.7.1 Human Interaction

Humans instinctively interact with their environment, either directly or indirectly with the tool or tools that are considered useful for humans; there are several categories of human interaction in conjunction with Human Computer Interaction and Human Vision and Electronic Imaging [90].

1. Real world interaction: In Figure 7, it can be seen that human beings interact directly to real objects in the environment, regardless of where the interaction took place, using tools or not. Humans actively interact directly against the object on the environment and assume that the object is useful for humans.

Figure 7 : Human Interaction in Real World [90]

2. Real-world interactions that lead to the virtual effects: In Figure 8, it is seen that human beings interact directly on the real object and then cause effects on the virtual world that has gone through the process of computing.

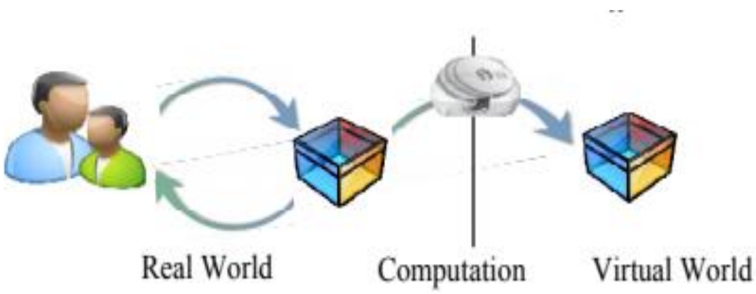

Figure 8 : Human Interaction Computed to Virtual World [90]

3. Virtual interaction: In Figure 9, virtual interaction by virtual humans on the environment and the direct effect of a virtual environment with the change of location in virtual environment.

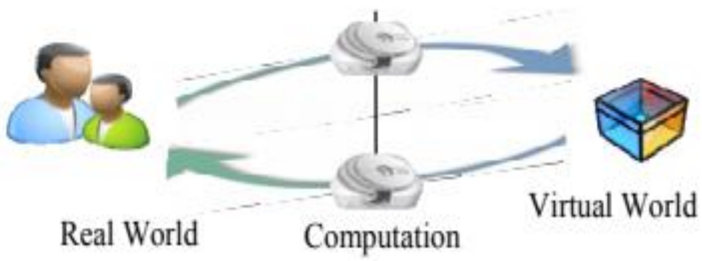

Figure 9 : Human Virtual Interaction [90]

2.7.2 3D Interaction

In interaction techniques development, 3D interaction techniques are used in development of VR and AR, where the technique include: (1)Interaction technique method for accomplishing a task, (2)3D applications that system displays 3D information, (3)3D interaction the user performing actions in three dimensions. Figure 10, shows interaction techniques position on the input device.

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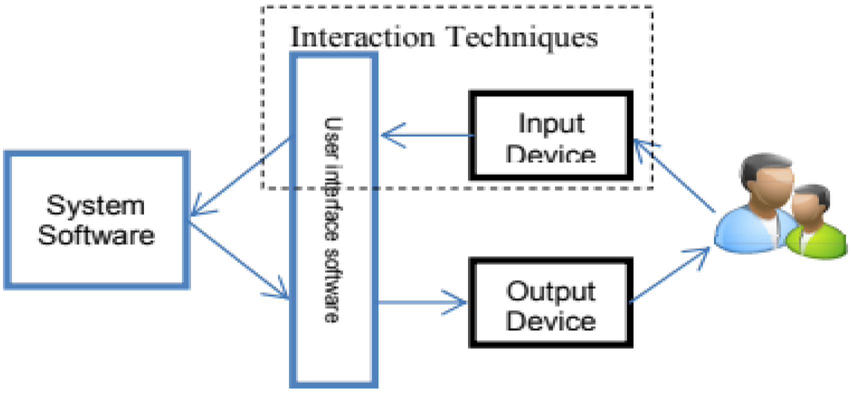

Figure 10 : Interaction Techniques in Input Device [90]

3D interaction techniques are methods for performing certain interaction tasks within the 3D environment. Interactions can be categorized into [91]:

1. Selection: It refers to selecting 3D object further interactions.

2. Manipulation: It means changing state of previously selected 3D object including the geometry. It normally immediately follows the selection of a virtual object.

3. Navigation: It is the process of setting the user's position and orientation relative to a 3D environment. This is one of the most basic VR interactions in which the user has the ability to move around and explore the virtual environment.

4. Creations: It is task of instantiating or constructing a new virtual object from scratch and adding it to the environment.

5. Collaboration: In projection-based environments, several users can work together interacting with the same application. In most display systems, this kind of interaction is not supported since only one user can be head-tracked and sees the correct perspective space.

6. Hand Gesture: Intuitive interaction techniques are major aspect of AR applications. Intuitive means, a user is able to manipulate virtual objects without aware utilization of prior knowledge. A major driver of intuitive interaction is vision based hand gesture recognition. Computer vision algorithms analyse a video stream, detect the user's hands and determine a gesture. The gesture fires an interaction function of the AR application that manipulates, for example, translate, a virtual object. Hand gestures and computer vision-based hand gesture recognition are assumed to approximate the natural interaction of humans closely. A user can interact with a virtual object like s/he interacts with a physical object using his/her hands [92].

7. Eye Gaze Interaction: Eye gaze is a type of modality that has shown to be potentially useful in situations where the users are unable to utilize their voice or hands due to disabilities or when the hands are needed for other tasks [93].

8. Head Gaze Interaction: The current best practice for hands-free selection using Virtual and Augmented Reality (VR/AR) head-mounted displays is to use head-gaze for aiming and dwell-time or clicking for triggering the selection [94].

2.7.3 3D Interaction Possibilities in VR

3D object interaction is a combination of performing several basic tasks within the virtual environment, similar to the ones used in the real world. Typically, a user is partly or fully immersed in 3D environment and can access its objects to control the application via 3D input devices [95] [91].

In interaction techniques development, 3D interaction techniques are used in development of VR, where the technique include: (1)Interaction technique method for accomplishing a task, (2)3D applications that system displays 3D information, (3)3D interaction the user performing actions in three dimensions [96]. These tasks include:

1. Selection: It refers to the process of identifying a 3D object for further interaction. This can be further subdivided into indicating the desired object, confirming the selection, and receiving a feedback [91]. Direct grasping, grasping an object with the hand, is the most intuitive selection technique. There are also several techniques that allow selection without moving, such as arm – extension and ray casting [95] [97].

2. Manipulation: It means changing state of a previously selected 3D object including its geometry, position, rotation and/or orientation in the virtual world. Manipulation can be further categorized into four control methods [63] [98]:

Direct user control: The interface gestures that mimic real-world interaction, thus the participant interacts with objects in the virtual world essentially as they would in the real world. Many direct user interactions combine the object selection process with the actual manipulation. This includes the use of hand tracking, gesture recognition, pointing, gaze direction, etc.

Physical controls: Are those that control the virtual world via a real-world apparatus. Because of the interface's real-world existence, the participant receives haptic feedback from pressing buttons and performing other actions. Common types of physical controls include buttons, switches with multiple position settings, slider and dial valuators, 2-degree of freedom (DOF) valuator controls like joysticks and trackballs, and 6-DOF controls such as the Magellan and Spaceball.

A virtual control: This is manifested entirely in the virtual world, thus just about anything you can imagine can be implemented as a virtual control. Many virtual controls are merely computer-generated representations of similar physical counterparts. Buttons, valuators, trackballs, and steering wheels are examples of physical controls sometimes emulated in virtual representations. Naturally, at some point the user must physically do something to activate a virtual control—either through direct, physical, or agent inputs.

Agent controls: Are those that allow the user to specify commands through an intermediary. That is, the user is in direct communication with an "intelligent" agent who will then perform the requested action. The agent can be a person or a computer-controlled entity. Communication with the agent can take the form of voice (the norm) or gestures like body language commands.

3. Navigation: This is the process of setting the user's position and orientation relative to a 3D environment. This is one of the most basic VR interactions in which the user has the ability to move around and explore the virtual environment. Full exploration of a large VE is only possible if the user is able to navigate through the environment. Often the VE is larger than the physical environment or beyond the tracking capabilities of the tracking system. These large VEs require navigation techniques to allow exploration without any physical movement by the user. Large VEs therefore offer "wayfinding" techniques which allow the user to determine his position. A distinction is made between three wayfinding tasks: naive search, primed search or exploration [91] [95].

4. Collaboration: In projection-based environments, several users can work together interacting with the same application. If the purpose of sharing the experience is to work together to solve a problem, that is to perform a task, then it is a collaborative experience. However, not all shared VR experiences are collaborative. Projection-based virtual environments frequently support perspective correct viewing for one user at most. Only very few systems have been developed to support multiple tracked users using a shared display, among those are the Two-User Responsive Workbench™ , which supports two individually tracked users, and the recently developed multi-viewer system at the Bauhaus University Weimar, which supports up to four tracked users. A basic collaborative selection and manipulation technique is the bent pick ray. The Bent Pick Ray is essentially a method for providing a useful visual feedback in situations in which objects are manipulated simultaneously by two or more users [28] [99].

2.8 VR Challenges

A paper by Sharmistha Mandal stated that some challenges in VR are improving tracking systems, finding more natural ways for users to engage in a virtual environment, and reducing the time it takes to create virtual settings. Another challenge for VE system developers is constructing a system that avoids bad ergonomics for example. Without well-designed gear, a user may encounter problems with balance or inertia, resulting in a decreased sense of telepresence, or he may experience cybersickness, which includes symptoms such as disorientation and nausea [100]. Another research mentioned that, for developing a proper virtual environment, high-performance computer systems or computers with high-performance processors are required. The same study also another challenge to cost; because these technologies are newer, they are more expensive, making them unaffordable for many small and medium-sized businesses [86]. Also utilizing VR solutions in the classroom can incur substantial overhead, in terms of the setup time, the software and hardware costs, as well as training of both students and educators [101]. Also ethical questions and challenges around VR technologies have been posed under the categories of *human rights*: security, data protection and privacy, *responsibility*: punishment, management versus individuals and laws and regulations , *mentality*: tolerance, trauma, understanding and state of mind, and *morality*: age (children versus adults), culture, experience [102].

In summary, VR as discussed in this chapter has a number of advantages and its application is widespread. Though it presents some challenges, the opportunities and avenues provided by VR make researchers, scientists, developers, companies, world market leaders, and so on to continue to revolutionize the technology to carter for its growing demand to be more accessible, affordable and of the utmost quality.

3 Education with and without VR

In psychology and pedagogy, several models have been proposed to explain the effects of learning. The theory of multimedia learning is the most important theory in this context. It is based on the assumption that a person's auditory and visual processing systems are different and each channel has limited bandwidth. Learning involves cognitive processes that link these representations together [103]. Also proposed was the Integrated Model of Multimedia Interactivity, which consists of six elements. The subject of learning activity is the *learner*, referred to personal characteristics, such as degree of prior knowledge and self-regulation, and affective traits such as self-efficacy and trait anxiety. The *learning environment* includes both the instructional design and the affordances of the learning system; *behavioural activities* describes what the learner does, physically, to interact with the learning system; *cognitive and meta- cognitive activities* are mental operations, procedures and processes which the learner performs in order to select, mentally integrate, organize and integrate new information into a coherent knowledge structure; *emotional and motivational states* are conditions of the learner that arise from the given situation. The result of the learning activity is the *mental model* which is used to refer to both the existing knowledge structures, and the gained knowledge [104].

In a literature cluster analysis, which explains the trends in VR studies [105], this field was the most researched, when knowledge acquisition and processing were rare , but from 2005 VR is often studied in the context of school and higher education [106] [107] [108] [109]. Early research on the use of VR in education primarily focused on the virtual worlds generated by desktop computers. The key result was that virtual environments enable students to familiarize themselves with abstract topics (such as the microcosm of bacteria) in specific ways [110].VR, which can be found in schools and universities as a 3D environment on a computer screen, interactive whiteboards, virtual worlds, games, or simulations, improves the efficiency of the learning process while also conforming to current technological trends, allowing students to adapt to new life situations. Simultaneously, the adoption of new technologies allow for a wider range of teaching approaches, because VR brings object visualizations as close as possible to real-world objects. Furthermore, it simulates environments that a person cannot visit in real life due to a variety of constraints. The educational process is more efficient and fascinating because of the novelty of VR technology and the realism of recreated VR environments, which elicit positive emotions and user engagement during the learning session, as evidenced by effective learning task completion utilizing VR. This is particularly evident when using game scenarios [111] [112]. Later, another research described features of educational 3D environments, including enhancing students' knowledge of spatial concepts; the ability to undertake tasks that would be impractical or impossible in the real world; and offering possibilities for students to participate within a multiplayer virtual environment. The use of VR for scientific, technological and engineering training enables students to experiment with numerous systems that cannot be modified in laboratory or industrial conditions. The outer shell of a product or mechanism for example, can be removed to reveal its internal structure and any changes in virtual environment can be easily reversed [113] [114].VR is mostly employed in skill training as a teaching approach. Manipulating objects in VR significantly improves the efficiency of skill learning, particularly for medical students' performance with surgical tools and execution of technical skills [115] [116] [117].

3.1 Learning Paradigms

For a study of the current state of VR applications in higher education, a thorough understanding of existing learning paradigms is required. Each learning paradigm has developed various theories about educational goals and outcomes and each of these theories offer a different perspective on the learning goals, motivational process, learning performance, transfer of knowledge process, the role of emotions, and implications for the teaching methods [118] [119].

The key concepts that underpin existing learning paradigms are:

Behaviourism: This assumes that knowledge is a collection of behavioural responses to environmental stimuli. Thus, learning is considered to be a passive absorption of a predefined body of knowledge by the learner. According to this paradigm, learning requires repetition and learning motivation is extrinsic, involving positive and negative reinforcement. The teacher serves as a role model who transfers the correct behavioural response [120] [121].

Cognitivism: This understands the acquisition of knowledge systems as actively constructed by learners based on pre-existing prior knowledge structures. Hence, the proponents of Cognitivism view learning as an active, constructive, and goal-oriented process, which involves active assimilation and accommodation of new information to an existing body of knowledge. Learners should be allowed to choose their own goals and motivate themselves to study since learning motivation is intrinsic. Learning is aided by creating an atmosphere that promotes knowledge discovery and assimilation or accommodation [120] [121]. Thinking, problem-solving, verbal information, concept development, and information processing are all seen as more complicated cognitive processes in Cognitivism. It deals with the ways in which the mind receives, organizes, stores, and retrieves information. Knowledge acquisition is a mental activity that involves the learner's internal coding and structuring. Digital media, such as virtual reality (VR)-based learning, can help to strengthen cognitivist learning design [122].

Constructivism: This posits that learning is an active, constructive process. Learners are active generators of information, actively creating their subjective representations and understandings of reality. Mental representations are subjective since new information is linked to each learner's existing knowledge [123]. As a result, constructivists claim that instructional learning design should give both macro and micro assistance to help learners generate knowledge and engage in meaningful learning. Related scenarios, information resources, cognitive tools, discussion and collaboration tools, and social or contextual help are all examples of macro support tools. A micro strategy employs multimedia and principles such as the spatial contiguity principle, coherence principle, modality principle, and redundancy principle to increase the learning process. The constructivist learning design is well-suited to VR-based learning [124] [125].

Experientialism: This defines learning as a series of experiential steps that progress from concrete experience to observation and reflection, abstract conceptualization, and finally testing concepts in new contexts. Experientialism contains some constructivist concepts, such as the idea that learning should be based on a learner's personal experiences [126].

Connectivism: considers the digital age by proposing that humans process information through connections. This new paradigm indicates that people continue to learn even after they have completed their formal schooling. They continue to use new technology tools to search for and receive knowledge outside of traditional schooling channels, such as job skills, networking, experience, and access to information [127].

3.2 Learning Framework and Model

3.2.1 Learning Theory Framework

J.Radianti et al extracted learning theory framework extracted from authors [128]. The categories include:

Behavioural learning: When students are rewarded or punished for correct or wrong answers, they may learn the possible consequences. This is true for VR applications that contain a system that allows students to learn—for example, responses that produce pleasant (rewarding) consequences or responses that produce annoying (punishing) consequences, or learning what the repercussions are for following or breaking the rules. Students learn when their actions result in specific outcomes, allowing them to adapt to their environments.

Experiential learning: When students learn through hands-on experience and then reflect on their experience using analytical skills. The student's judgment, sentiments, or skills change as a result of these reflections.

Generative learning: When students engage in cognitive processing during learning, such as selecting (i.e., paying attention to relevant incoming information), organizing (i.e., mentally arranging the information into a coherent structure), and integrating (i.e., connecting the verbal and pictorial representations with one another and with relevant prior knowledge activated from long-term memory)

Operational learning: Students can interact, select, grasp, move, point, and place objects to learn computer assembly when they are learning how to construct or assemble an object.

Game-based learning: When students learn through a gamification process, which involves incorporating game design features and mechanics, such as points, levels, and badges, as well as game dynamics, such as rewards, statuses, and competition, into the learning process.

Contextual learning: When students learn by emphasizing the context, i.e., the set of circumstances that are relevant for the learners to build their knowledge. As a result, the learning content can aid students in acquiring insights through balanced, organic, and effective environments and methods.

Jeffries simulation theory: When students learn through a simulation process and gain experience in a safe setting that is incorporated in the VR design.

Cone of learning theory: When students learn through both active and passive learning methods, such as hands-on or field experience, they get direct, purposeful learning experiences. According to this notion, learners learn best when they have a real-life experience or when that experience is realistically recreated [128].

3.2.2 A Model for Understanding How Virtual Reality Aids Complex Conceptual Learning

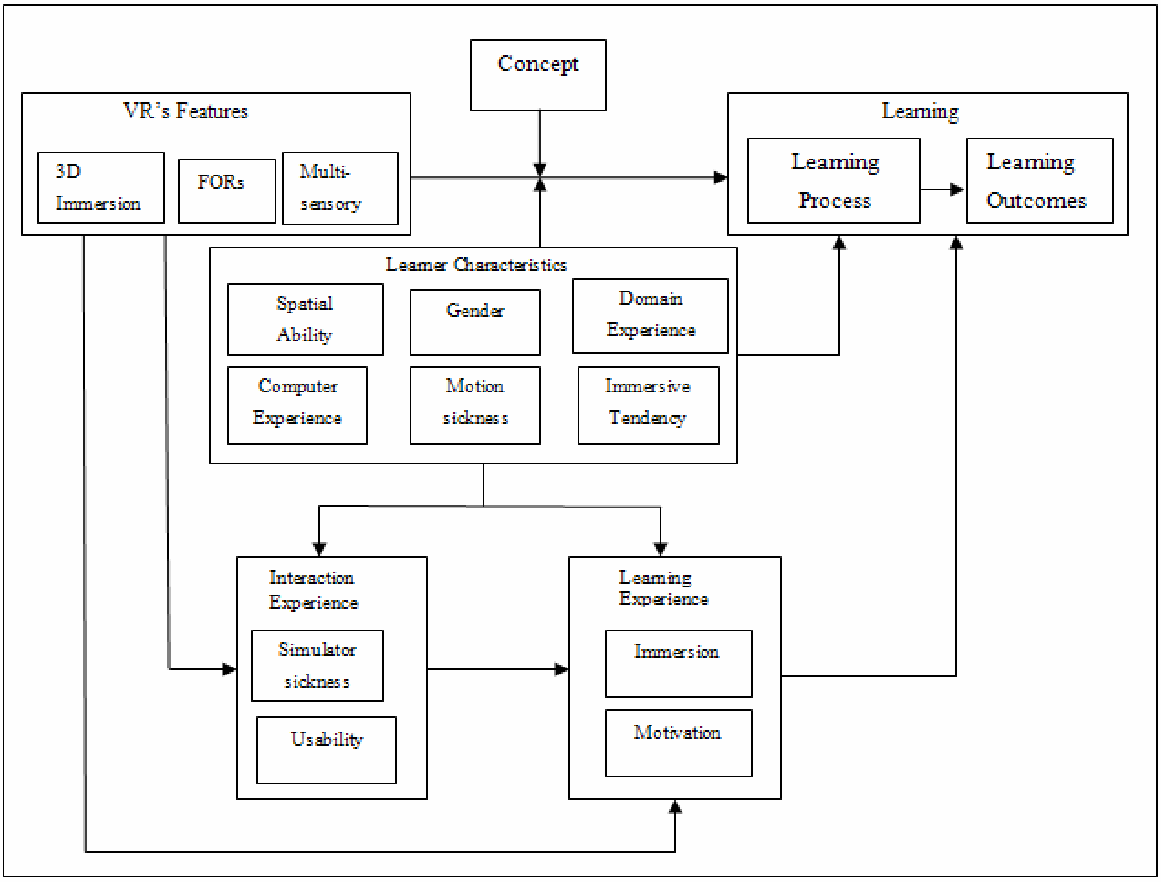

Figure 11 : A Hypothetical Model Showing Relationship between VR's Features, Concept, Learner Characteristics, and the Interaction and Learning Experiences [129]

The model above suggests [129]:

1. VR Features: The three characteristics are 3-D immersion, frames of reference (FORs), and multisensory cues.

- 3-D immersion: Users form the subjective impression that they are part of a "world" that is both comprehensive and real enough to encourage willing suspension of disbelief. These representations can be inspiring and can help students learn in ways that are not possible with traditional methods.
- FORs: According to psychological study on spatial learning, navigation, and visualization, perspectives, or frames of reference, bring salient different aspects of an environment and influence what people learn. Flexible FORs can be motivating and facilitate the learning process.
- Multisensory cues: Users can receive information by interpreting visual, audio, and haptic cues while using their proprioceptive system to navigate and control objects in the synthetic environment using high-end VR interfaces. This has the potential to improve learning and memory and can be used to direct students' attention to enhance the quality of learning and interaction experiences.

2. Concepts: Refers to what one is being asked to learn. Different VR features are appropriate for different concepts. The effectiveness of 3-D or multisensory representations may be affected by the topic being taught. VR features sometimes support the learning of one concept while hindering the learning of another.

3. Individual characteristics: Over time, several learner characteristics likely to be important have been identified as: gender, domain experience, spatial ability, computer experience, motion sickness history, and immersive tendencies. The first three elements are significant because they may have an impact on a person's ability to grasp abstract scientific concepts. Spatial ability is the cognitive ability that enables individuals to perceive patterns and to manipulate and rotate that information relative to one's own position in space. Students' spatial abilities may have a significant impact on how efficiently they use the information offered by VR features. Spatial ability, along with computer experience and motion sickness history, may also influence the interaction experience. Finally, immersive tendencies may be effective in predicting how immersed a student will get in a VR learning environment.

4. Learning experience: According to current research, VR features have an impact on the learning experience. Some learning experiences include motivation, perceived meaningfulness, presence which in turn also influences learning.

5. Interaction experience: This refers to how easy the user can interact with the system. VR's features have been shown to effect usability and simulator sickness. However, usability, which can be performance usability or subjective usability, can sometimes aid in learning and hinder it at other times.

6. Learning: This comprise of the learning process (or the types of information one attends) and the learning outcomes (or a person's level of knowledge after the lessons are completed).

In summary, VR's features, the concept one is being asked to learn, learner characteristics, and the interaction and learning experiences work together to influence the learning process and learning outcomes in VR learning environments.

According to an interview in (Appendix 5), it also became clear that enthusiasm has a great influence on our learning behaviour and also on learning success. Again, concentrated learning is possible over a period of 45 minutes, everything beyond that is only processed in a fleeting manner and cannot be accessed in the long term.

3.3 The Application of VR technology to Teaching Reform [130]

In the field of education, VR technology has added new vigour and vitality. VR technology can support education innovation in the sector of education. VR actively promotes reforms of teaching concept, teaching methods, teaching contents, teaching measures.

A. Changes in Teaching Concepts

Virtual classrooms, virtual labs, virtual library, virtual campus, and other educational technologies emerged as a result of the advancement of VR technology, injecting new life into the area of education and promoting changes in teaching concepts. VR technology can simulate teaching in the sense that teachers can provide a range of teaching content that their students require using VR technology allowing students to learn independently. On the other hand, VR technology can also simulate vivid, life-like learning environment for students, allowing them to obtain knowledge from a wide range of subjects.

The implementation of simulation functions has altered traditional teaching approaches, which prioritized the ‘‘student-centered" and ‘‘teacher-led, student-centered" teaching modes. Through the establishment of virtual teaching platform or the deployment of VR technology, it mobilizes student initiative and is favourable to student learning and reflection. Students can be assigned to a teaching guide based on their individual characteristics using the interactive feature of VR technology, and they will make significant academic progress.

B. Changes in Teaching Methods

The behaviour adopted by teachers and students during teaching and learning activities in order to fulfil teaching objectives and teaching requirements is referred to as teaching methods. Lectures, talks, demonstration, visit, experiment, practice, discussion, reading guidance, exercise and other approaches are all workable teaching methods. The above-mentioned methods cannot play a significant role because of limitations of incompetent teachers, lack of education funding, insufficient space in colleges and universities. Intelligent agents can be utilized as virtual teachers in the learning environment, and they can take on the roles of "navigation" and "answer" to lead and assist students in gaining the learning resources they require. VR technology can prevent ‘‘information" from being filtered and ‘‘resources" from being lost. It can respond to students' questions according to the network teaching resources.

The implementation of virtual counselling allows students to obtain guidance in the absence of an instructor and improve their self-learning abilities. Virtual teachers and counselling enable students and teachers to learn, communicate and discuss outside of the limits of learning time and place. VR technology will boost the fun and user-friendly colour, hence improving educational efficacy.

C. Changes in Teaching Contents

Instruction on the content varies according to distinct teaching programs at various schools. The teaching environment has a significant impact on the structuring of the educational content. Some courses are not available at many colleges and universities because of insufficient teaching resources. Boring, abstract and difficult to understand are all common characteristics of school teaching. As a result, students will lose interest in learning and will have difficulty comprehending the contents. When VR technology is used in the classroom, the educational content undergoes significant modifications in both exterior form and internal structure. To replicate reality, the external mode of education can use a three-dimensional virtual scene. The external form of teaching can use three-dimensional virtual scene to simulate reality. VR technology may show changes that cannot be seen, things or dangerous areas that cannot be handled, and even events that do not exist in the natural world or in real life. In addition, VR technology allows a variety of media material to be merged, organized and shown, and knowledge structure to be built using the characteristics of human cognitive approach throughout the teaching content organization process This network information organization is a non-linear structure that may effectively integrate information formation organization and diversity, complexity, and give students with dynamic, open, structural cognitive forms.

D. Changes in Teaching Measures

Due to the increasing amount of teaching work and teaching effect expectations, traditional teaching measures are unable to match the age requirements for education. VR technology allows for more precise and cost-effective teaching measures. As a way of direct information transmission, VR technology provides visual, multisensory audio-visual contents. It is introduced into teaching as a new sort of instructional media that delivers virtual reality scenarios for teaching, allowing students to feel deeply engaged in the scenes, and motivating their enthusiasm.

Teachers and students can interact using VR technology, which offers a kind of "self-learning" setting in which teachers function as instructors and students gain knowledge and skills by interacting with the information environment and themselves. Furthermore, VR technology may vividly demonstrate abstract concepts, teaching principles, and create a "virtual" learning environment to assist students in grasping the core of the concepts. Also, through analysis, synthesis, comparison, induction, reasoning, and other high-level thinking skills, VR technology allows students to demonstrate around the assumption, getting closer to grasping the truth, which is beneficial for the development of discovery learning styles and the cultivation of high-level thinking skills in students.

3.4 Anatomy in Medical Education

Anatomy is widely recognized as one of the most important aspects of medical education. Anatomy learning content can be categorized into the following modalities: dissection/prosection, interactive multimedia, procedural anatomy, surface and clinical anatomy, medical imaging, artificial models, body painting, and digital anatomy [11].

1. Dissection/Prosection: This involves teaching gross anatomy with cadaveric dissection and/or prosection preferably with demonstrators present. Active observation and participation in cadaveric dissection helps the understanding of three-dimensional (3D) structures through curiosity and self-exploration [11].

A number of advantages include: development of cognitive anatomical knowledge and vocabulary; an understanding of three-dimensional relationships as well as anatomical variation; establishing a tissue classification system; laying the foundations for the study of other disciplines where knowledge of structure is essential (e.g. physiology, microbiology and pharmacology). The development of fine motor control and a touch-mediated perception of the cadaver patient, as well as proficiency in diagnostic imaging and training for medical specialties, are all skill-based benefits [12]. Dissection of cadavers may present with a number of problems : the colour, texture and smell is not like real life, they cannot be palpated, auscultated or usefully asked to change position, their use may present health hazards and ethical/legal difficulties, and the high expense of maintaining a cadaveric facility means the cost-benefit ratio of using them must be carefully weighed [131].

2. Interactive multimedia: This involves teaching anatomy with computerized learning packages so that students know exactly what to expect beforehand and how to make the most of their short time in the dissection room. This include web-based computer-aided instruction resources such as web-streamed lectures and instructional videos, internal imaging atlases and projections of major organs onto body surfaces compiled onto an interactive CD-ROM, a mobile-based application and interactive 3D atlas computer software, interactive online e-learning modules, DVD demonstrations and web-based multimedia animations [11].

3. Procedural anatomy: Clinical procedures necessitate a detailed understanding of anatomy, especially for emergency protocols on either cadavers or plastic models. An online syllabus, videos, and lectures, as well as hands-on practice using unembalmed cadavers, models, and ultrasound, are used in an advanced emergency procedural training program at the University of California [132] [11].

4. Surface and Clinical Anatomy: This anatomy is applicable to patient care as anatomical landmarks and clinically relevant structural outlines are defined. Physical examinations (by inspection, percussion, palpation, auscultation, and instructions) can be practiced extensively early in medical school to prepare for life-long clinical interaction [11].

Medical education curriculum frequently use simulated or “Standardized” patients as tools to assist students gain skills in clinical reasoning, physical examinations, history-taking, patient diagnosis and generalized doctor-patient relationship. Standardized patients are typically people of the community who have been trained to portray a specific ailment or condition. While standardized patients are an important component of medical education, creating and maintaining a high-quality standardized patient program can be expensive and time-consuming. In addition, students often have to work in fairly large groups and often only have brief interactions due to the limited numbers of standardized patients available [133] [134]. Also peer examination involving students examining each other on a consented basis as well as life models, individuals who are comfortable being undressed and observed in a public setting, can also be used in this category [131].

5. Medical Imaging: The technique and process of imaging the interior of a body. In both diagnostics and anatomy education, this has become increasingly significant. Radiology education allows students to see anatomy and physiology in real time, as well as gain insight into pathological processes [11]. Ultrasound is largely regarded as the safest and least intimidating method for viewing inside the body. CT and MRI allow deeper exploration of the body in different dimensions. Also, X-rays provide some usefulness but many anatomy courses dedicate less time to their application [131].

6. Artificial models: They comprise plastic ‘models’, or replicas that represent either surface or gross anatomies for educational purposes. Plastic models are simple, withstand frequent handling and have a longer shelf-life than cadavers. They help students to develop a simple overall mental map of internal anatomy, and when used in super-sized forms, they aid understanding of complex phenomena such as hearing and swallowing, because they are coloured in ways that depict internal organs and muscles. Texture, weight, and what they do not display are some of their drawbacks [131].

7. Body painting: This involves painting internal structures on the surface of the body with high realism. Structures like the heart and pericardial cavity, and lungs and pleural cavities can be painted in realistic colours onto the bodies of students and life models. It has been an additional visual aid in surface anatomy classes [131]. Body projections use simple technologies like data projectors and PowerPoint to project anatomical images onto the surface of the living human body [131].

8. Digital anatomy: They are computer-based three-dimensional modelling of the human body. Digital anatomy have benefitted from the computer and communications technological revolution and lies at the intersection of converging disciplines, ranging from medical imaging, medical visualization, 3D printing, and computer graphics to artificial intelligence and robotics. Virtual, augmented and mixed realities applications are implemented for educational anatomy [135].

According to an interview in (Appendix 5), it also became clear that for the future, first contact with newer technologies such as augmented and virtual reality is necessary to be given during medical studies. However, the adaptation times to virtual reality should also be observed. Also anatomy or surgical atlases cannot be completely replaced because they have made significant progress over the years and can now be supported in the current age with multimedia support via app on the mobile phone, via a didactically perfectly structured program on the computer or even virtual reality.

Figure 12 : Some Anatomy Learning Modes [136]

3.4.1 Virtual Anatomy

Virtual Anatomy is a technology tool that allows users to visualize and learn anatomy in an interactive manner. Learners, educators and professionals can use this digital anatomy to study, teach and better understand the human body. The tools include 3D models, videos, informative labels, animations, quizzes and more. There are many types of virtual anatomy learning, including the incorporation of virtual cadavers, Radiology (RAD) workstations, ultrasound sessions and volumetric reconstruction on CT and MRI. Each type of virtual anatomy aids in the teaching of essential skills and procedures for a variety of healthcare professions. Regardless of the profession, the knowledge also helps in the general understanding of bodily functions [137].

3.4.1.1 Virtual Anatomy Teaching System

A complete virtual anatomy teaching system contains a variety of anatomical teaching materials, such as a human morphological three-dimensional (3D) model, anatomical knowledge ontology, an anatomical specimen map, and a video of anatomical operations. The development of a virtual simulation system would be designed to meet the requirements of the educational objectives. The basic steps in the development of a virtual anatomy system are shown in Figure 13 [138].

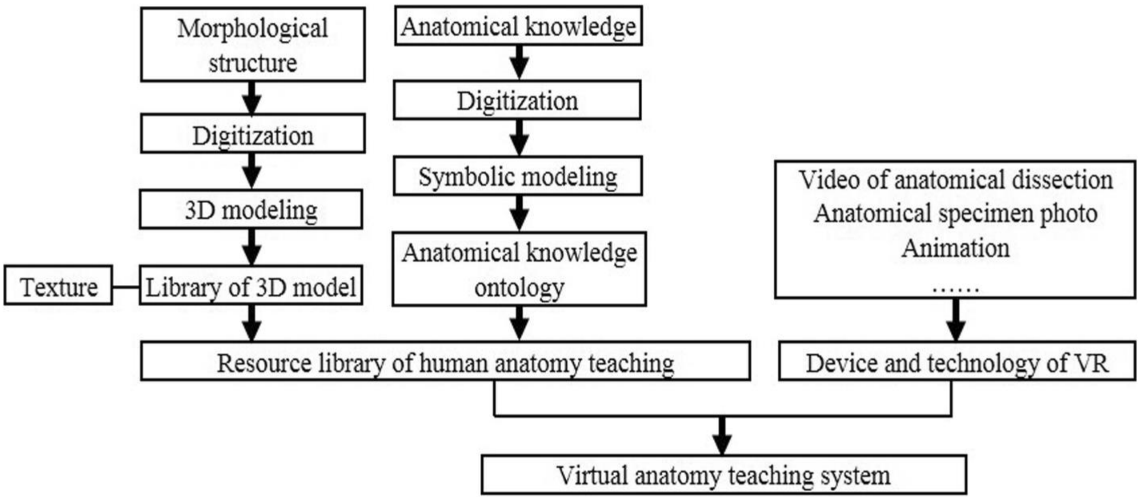

Figure 13 : Basic Steps in the Development of a Virtual Anatomy System [138]

The development of a virtual anatomy teaching system includes the following aspects:

(1) digitization and modelling of human morphological structure to construct a 3D model library with texture; (2) digitization of anatomical knowledge and modelling symbols to construct an anatomical knowledge ontology; (3) semantic association of the 3D model library, anatomical knowledge ontology, and conventional anatomical resources (such as videos, maps, animations, etc.) to construct a resource library of human anatomy teaching; and (4) construction of a virtual anatomy teaching system appropriate for the particular teaching purpose using VR devices and technology.

The virtual simulation of anatomical teaching systems must address three core issues: modelling, perception, and interaction. Modelling refers to the kind of model to be built and the construction of specific models to meet the needs of virtual simulation; perception refers to the kind of knowledge and experience that needs to be communicated by the system, as well as how they can be effectively perceived by the learner and whether the perceived content is required by the learner; interaction refers to ensuring that the form of interaction with the system is an effective means of knowledge dissemination [138].

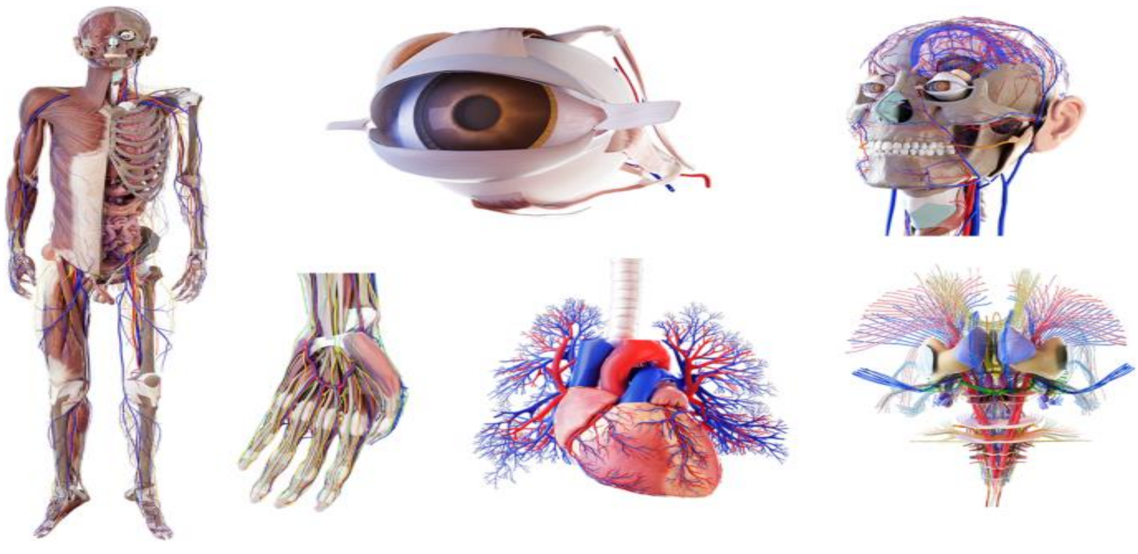

Figure 14 : Examples of the virtual anatomical models [138]

3.5 Anatomy of the Heart

This thesis explores the use of two learning approaches, VR and a traditional method, PowerPoint, for the purpose of their effectiveness in cardiac anatomy learning, study of the heart, especially anatomical knowledge for biomedical engineering students.

The heart is one of the challenging topics to teach and understand due to its complex three-dimensional nature and details. Regardless of their complexity, accurate recognition of these details is a pre-requisite for the subsequent understanding. The heart, located in the centre of the chest, beneath the sternum in a thoracic compartment, is primarily responsible for pumping blood and distributing oxygen and nutrients throughout the body. Because of its function, the heart is regarded one of the most vital organs in the body, and even little malfunctions or anomalies can result in significant changes or effects on the human body [139] [140].

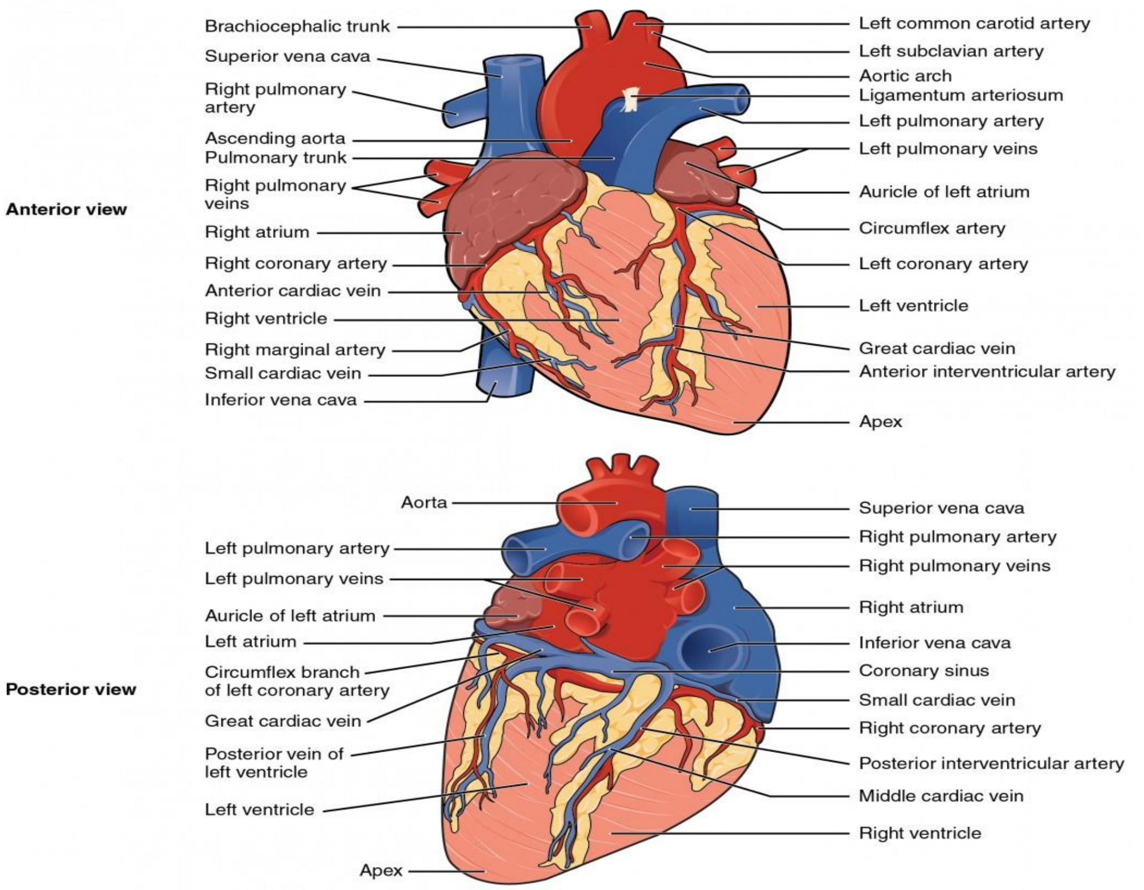

Figure 15: Anterior and Posterior External Surfaces Features of the Heart [140]

The major components of the heart are:

1. Four chambers: Two upper chambers , the right atrium and left atrium , acts as a receiving chamber and contracts to push blood into the lower chambers, the right ventricle and the left ventricle. The ventricles serve as the primary pumping chambers of the heart, propelling blood to the lungs or to the rest of the body.
   - Right atrium: This chamber receives deoxygenated blood from the body collected into the inferior and superior vena cavae.

- Right ventricle: This chamber receives deoxygenated blood from the right atrium through the tricuspid valve.
- Left atrium: This chamber receives oxygenated blood from the lungs through the pulmonary veins.
- Left ventricle: This chamber receives oxygenated blood from the left atrium through the mitral valve and ejects it into the aorta through the aortic valve.

2. The pulmonary arteries: They carry deoxygenated blood pumped from the right ventricle into the lungs where gas exchange occurs: Carbon dioxide exits the blood and oxygen enters.
3. The pulmonary trunk veins: They carry oxygenated blood returning from the lungs into the left atrium.
4. Aorta: Carries oxygen-rich blood from the left ventricle of the heart to other parts of the body.
5. Coronary arteries: They branch from the base of the aorta and supply vital oxygenated blood to heart muscle.

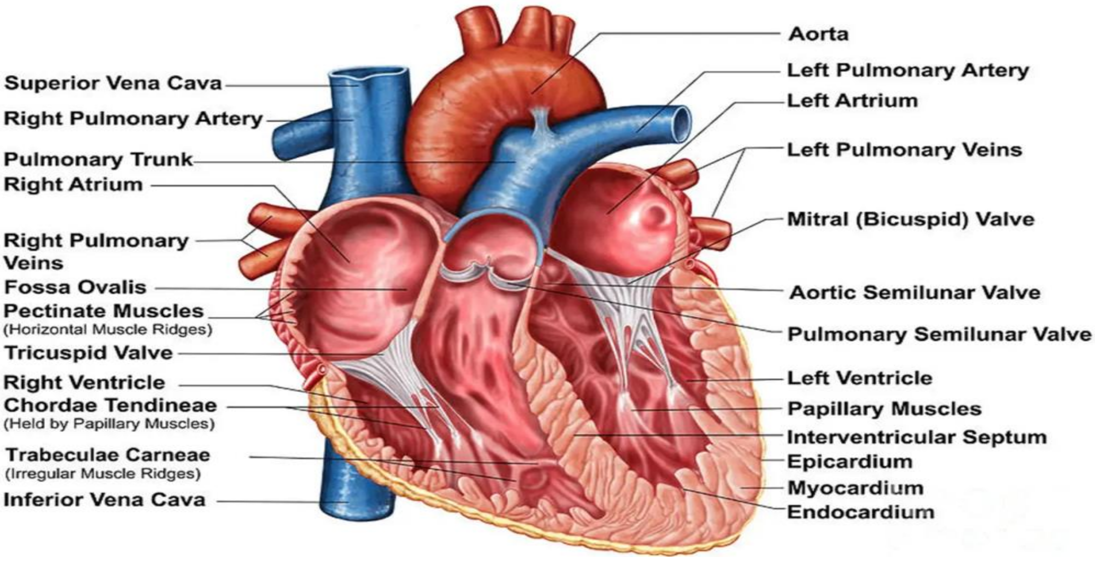

Figure 16 : Internal Features of the Heart [141]

6. Four valves help close the connection points between these chambers, preventing blood from back flowing. The valves between the atria and ventricles are known generically as atrioventricular valves. The valves at the openings that lead to the pulmonary trunk and aorta are known generically as semilunar valves.
   - Mitral valve, two leaflet valve, separates the left atrium from the left ventricle.
   - Tricuspid valve, three leaflet valve, separates the right atrium from the right ventricle.
   - Pulmonary valve separates the right ventricle from the pulmonary arteries as blood travels to the lungs.
   - Aortic valve separates the left ventricle from the aorta as blood travels to the body.

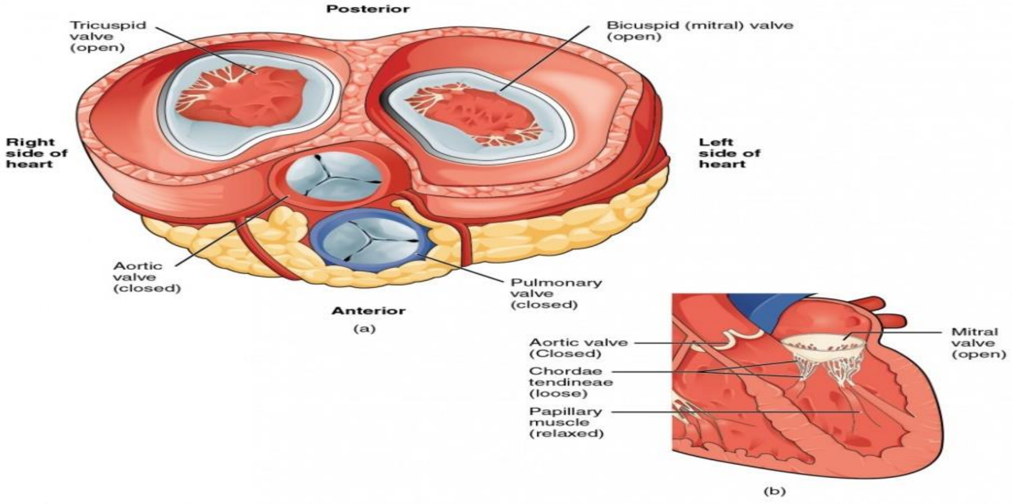

Figure 17 : Heart Valves a) Transverse Section b)Frontal Section through the Heart [140]

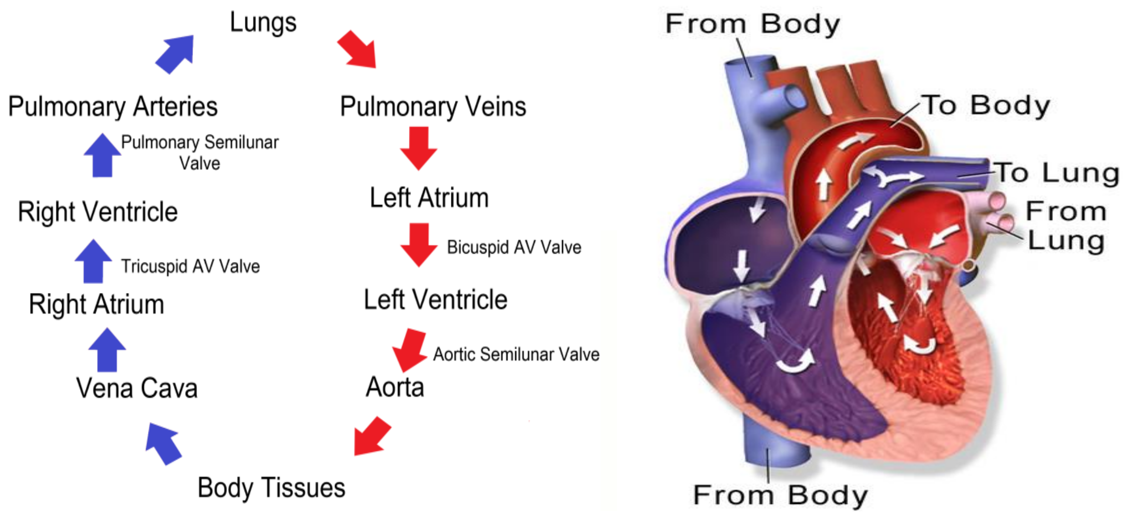

Figure 18 : Heart Blood Flow Pathway [142]

The biomedical use case is in the form of teaching the heart with an immersive 3D heart model in a virtual environment and PowerPoint presentation which will be further discussed in chapter 5.

3.5.1 Cardiac Applications of VR

In cardiology, VR has found uses in education, preprocedural planning, intraprocedural visualization, and patient rehabilitation.

Education: For educational and training purposes, VR offers a wide range of opportunities. Some applications take advantage of VR's immersion to recreate the full operational environment as well as educational content. Another set of applications extend existing medical simulations for tablets and smartphones to VR as the next platform for trainees to use. Most consumer VR platforms support these VR use cases [143].

1. Stanford virtual heart [144]: In collaboration with Lighthaus, Inc., the Stanford Virtual Heart Project (18) uses an immersive VR headset for educational purposes. There are a few different aspects to this

project. The first is aimed at patient and family education, with the goal of helping families better comprehend their child's heart structure, which is now only represented by drawings and plastic models. Parents should be able to better participate in their child's complex medical treatment as a result of their enhanced understanding. This application has been made available to Stanford medical students and trainees, who can use it to visualize normal and abnormal anatomy and learn how congenital defects affect physiology. The final application is in the cardiothoracic operating room, where a 3D monitor called Echopixel (described later in the section "Pre-Procedural Planning") is used. A 3D workstation in the operating room could help doctors examine intracardiac anatomy and geometry, which can be difficult to observe after patients are put on cardiopulmonary bypass and the heart is decompressed.

2. HoloAnatomy [145] : Investigators at Case Western Reserve University are using Microsoft's Hololens to transform medical student teaching, particularly anatomy. Understanding 3D anatomic relationships not only makes studying easier, but it also motivates students to "think like a doctor." In collaboration with the Cleveland Clinic, the team at Case Western Reserve University is creating HoloAnatomy, a curriculum that will allow medical students to conduct holographic dissections to better grasp and understand the body's organs and systems. This software's preview versions are available for free download.

Pre-procedural planning: The True 3D system developed by Echopixel, integrated into a diagnostic grade DICOM workstation, is one of the first 3D displays to be approved by the US Food and Drug Administration. The Echopixel technology was used in the first cardiology investigations to visualize arteries in patients with pulmonary atresia and large aorto-pulmonary collateral arteries [21] [147]. VR can be used successfully for surgical planning in paediatric and congenital cardiac surgery, and it should be developed in centres that can afford to invest in this cutting-edge technology [148].

Intraprocedural visualization: VR also has the potential to improve intraprocedural visualization, which currently relies on techniques such as fluoroscopy, electroanatomic mapping systems, and echocardiography (intracardiac echocardiography and transesophageal echocardiography). The latest prototypes allow visualization of patient-specific 3-dimensional cardiac geometry with real-time catheter locations [143].

Rehabilitation: There are rehabilitation applications for virtual reality that have also been approved by the US Food and Drug Administration. Patients recovering from stroke can use a combination of virtual reality, brain imaging, and gaming technologies to retrain the brain and improve upper limb mobility [143].

4. Literature Research

VR technology has been applied in several areas with constant pursuit for new advancements and developments. Previous and current applications of VR in education, medical education as well related work in its application to specific anatomic regions for example the heart is discussed here. In recent years, these VR features have widely been extensively used in the educational process, but with mixed results. Many researches on the use of VR in education have found that it has a positive effect and this is also supported with the meta-analysis where studies were classified as using traditional (lecture, text- book, paper-based exercise, 3D concrete models, or physical lab sessions), multimedia treatment (videos, graphics, or computer-based tutorials), combination (desktop-based virtual reality, traditional or multimedia methods) and no treatment in the control group [117] [116] [149] [107] [111] but hybrid teaching modalities would undoubtedly contribute to better understanding and retention [11].

4.1 State of Art: VR Case Studies in Education

A recent meta-analysis focused on how IVR was used in post-secondary level education and skill training, have found a positive outcome for high immersive VR delivered through HMD, after comparing with other platforms such as desktop display screen, 2D video, mobile phone, digital tablet or stereoscopic desktop display screen [150].

The award-winning MARLA research project shows the potential of innovative interfaces of augmented and virtual reality (XR) technologies, digital language aid, and serious games for practical use in commercial-technical training using the example of wind energy technology. Also, a learning application is being developed and tested for the occupational sectors of electrical engineering and metal technology. The target group of this project are vocational trainees in the field of wind energy technology. Participants are not exposed to the weather-related and various mechanical and electrical hazards when performing specific problem-solving scenarios, like repairing a wind turbine, but can try out in a protected space [151].

A study discussed the importance and superiority of virtual reality technology in aesthetic teaching, looked for a method and way to improve the aesthetic teaching effect of an art design major, and investigated the virtual reality technology application strategy in aesthetic education, all in the hopes of providing a reference for the reform and advancement of aesthetic teaching in this specialty. It was concluded that, the use of virtual reality technology in aesthetic teaching of art design-related disciplines can improve the artistic effect of aesthetic education while also contributing new information technology to art education [152].

Afonseca et al. developed a marine life game designed for children with Down syndrome, with focus on collective learning in small group settings. Students could observe virtual marine life move about in its 'natural' habitat. Students were also asked to participate in simple identification activities and quizzes, such as ranking animals in the food chain. The software was designed to appear informal, fun and inviting to users. The findings indicated high level of acceptance of the system as a useful tool for both instructors and users in the learning experience. Furthermore, the findings justified the usage of the system with multiple down syndrome users [153].

The Universitat Politècnica de Catalunya in Barcelona, Spain, pioneered the notion of a multiplatform virtual laboratory for educational purposes. This virtual laboratory offers university-level control system experiments. For programming, EJS (Easy Java Simulation), a Java language-based tool, and Matlab are utilized. This multiplatform virtual laboratory offers two types of experiments: magnetic levitator and inverted pendulum-cart system. Experiments in the virtual laboratory emulate real educational equipment, a Magnetic Levitator (MagLev). Different experiments can be performed and, in all of them, the student can see the levitating ball movements in real-time [154].

VR was used as an empathetic teaching tool. Here, the University of New England introduced an innovative new teaching modality using VR to teach medical and other health professions students to be more empathetic with older adults. The software simulated being a patient with age-related disease and also provided information resources to familiarise themselves with the health of older adults. According to the findings, VR improved students' understanding of age-related health problems and increased their empathy for older adults with vision and hearing loss or Alzheimer's disease [155].

H.Sirror et al reviewed VR for architecture education reasoned by the emergent need for e-learning due to lockdown measures declared by World Health Organization (WHO) in March 2020 as a counteraction to the global Pandemic, COVID-19. An online alternative to the substantial practical content was sorted after due to the challenging nature of architecture. Hence, the paper presented a brief study on VR and its applications of implementation in architecture education and also reviewed the main VR applications that were implemented in the four primary areas of architecture education, including design, construction, surveying, and structural analysis and design. Results showed adopting VR technologies improved learning among students [9].

B. Lok et al investigated the application of VR in medical communication education. The paper presented current findings and potential teaching and learning benefits of immersive virtual patients. According to the findings of this study, the virtual patient was not nearly as expressive as the standardized patient. Overall, in terms of the educational value of the experience, students rated the virtual and real scenarios equally. Despite the system's flaws, the virtual interaction obviously matched educational goals [156].

4.2 State of Art: VR Case Studies in Medical Education for Surgery

VR Multi-user Conference Room for Surgery Planning [157]: Researchers presented a prototype for a virtual conference room surgery planning on the liver, where multiple physicians from different locations benefited from interaction with 3D liver organ models as well as 2D grey-value images. The system also enabled the discussion of the surgical problems over distance. Two liver surgeons assessed the prototype and found it helpful for surgery planning. The multi-user aspect enhances this impression further, as the two physicians could point at areas of the liver and discuss a strategy together. However, they criticized the appearance of the avatars. Reasoned by the inverse kinematics approach, the physicians' real body posture and virtual posture were not corresponding from time to time. This reduces the feeling of body ownership and, thus, the perceived immersion.

Virtual Reality Training Curriculum for Laparoscopic Colorectal Surgery [158]: This paper designed and validated a virtual reality competency-based curriculum for an advanced laparoscopic procedure: sigmoid colectomy. It was found that, such training may reduce learning curves, enhances performance during real surgical procedures and improve patients' safety in the operating room, as junior surgeons have limited access to these complex procedures.

Virtual reality training tool for orthognathic surgery [159]: In this study, a training tool for Le Fort I osteotomy based on immersive virtual reality (IVR) was developed and validated. The application was tested for face and content validity by seven consultant oral and maxillofacial surgeons. They evaluated the content of the developed training tool, its realism and usability, and the applicability of VR surgery for orthognathic surgical training. The results confirmed the clinical applicability of VR for delivering training in orthognathic surgery.

VR as a robotic surgical simulator (RoSS) in pelvic surgical anatomy training [160]: This paper evaluated the efficiency of a robotic simulator in pelvic anatomy training amongst ten surgical trainees. They were equally divided into two groups: group I studied the syllabus and group II similarly studied the syllabus, but were trained on the RoSS system using cognitive skill sets. Both groups took a test and all results were statistically significant. However, it was concluded that RoSS is an effective tool in anatomy training because in group II, the mean number of correct answers was higher and the mean number of errors committed was lower.

4.3 State of Art: VR Case Studies in Medical Education for Specific Anatomic Regions

A meta-analysis study by J. Zhao et al aimed to examine the general efficiency of VR for teaching medical anatomy. They targeted students' examination scores as primary outcomes and their degrees of satisfaction as secondary outcomes. According to their results, VR improves post-intervention test score of anatomy compared with other types of teaching methods, traditional or 2D digital methods. In terms of the satisfaction scores, VR is significantly in favour. They concluded that VR is an efficient way to improve the learners' level of anatomy knowledge [2].

D.T. Nicholson et al presented VR technology for anatomy education of the ear. They reconstructed a fully interactive model of the middle and inner ear from a MRI scan of a human cadaver ear and conducted a study in which 28 medical students completed a Web-based tutorial on ear anatomy that featured the interactive model, while a control group of 29 students completed the tutorial without being exposed to the model. The intervention group's mean score was statistically different from the control group [16].

Marks et al provided an example for an immersive system of the nasal cavity. The depiction of airflow which was calculated using a computational fluid dynamics simulation is a fascinating addition to the visualization of the 3D structures. Their user study was conducted with mechanical engineering students as a part of their coursework. Despite the fact that medical students were not involved, the qualitative feedback reveals that their educational VR application has benefits for the students in terms of engagement, understanding and retention [161].

K. Stepan et al presented a VR system for anatomy education of the brain. This research compared the supplemental use of the neuroanatomy VR model to the use of only online textbooks in 66 medical students. The primary outcome was an improvement in achievement on the three anatomy knowledge quizzes. According to findings, there was no significant difference in anatomy knowledge between the 2 equally randomised groups on pre-intervention, post-intervention, or retention quizzes. The authors came to the conclusion that immersive VR educational tools provided a more positive learner experience and enhanced student motivation. However, the technology was as effective as the traditional text books in teaching neuroanatomy [162].

Maresky et al presented another comparative study with 42 undergraduate first year medical students. Here they focused on cardiac anatomy on the basis of its complex three- dimensional nature. They had two randomized groups: the experimental group using immersive cardiac VR and the control group used cadaveric dissection to learn the heart. In contrast to the study by K. Stepan et al [162],significant difference between the VR group and the cadaveric group could be found. Overall, the objective and subjective results of this study demonstrated that VR is a fun and effective tool for teaching normal cardiac anatomy, yielding a performance increase of 24.6% ($p < 0.0001$) in the experimental group over the control group [1].

Another study which also focused on the heart was presented by Y.P Zinchenko et al. In this study three randomized groups of students, who did not have biological and medical classes amongst their courses, studied human heart anatomy using three different learning methods – a paper (text and images); a 3D interactive human heart model presented on a computer display; and an Immersive VR human heart model. The students performed a pre- and post-intervention quiz with 28 open questions. The IVR group showed the increase of correct answers within the group and compared with other groups. In conclusion, studying in the IVR environment was found to be more efficient, than reading texts or interacting with a 3D model on a computer screen [10].

J.Falah et al. developed a VR and 3D visualisation system for anatomy teaching. The system offered a real-time 3D representation of the heart in an interactive VR environment that provided self-directed learning and assessment tools through a variety of interfaces and functionalities. The developed system was based on users' requirements and in depth medical doctors' consultations. A group of medical professionals evaluated the system and overall, the results were encouraging with only minor improvements required as feedback [15].

4.4 Approach

Based on aforementioned literature research, VR has been a valuable tool for educational purposes, particularly in the medical education field. Due to this, this thesis explores, the effectiveness of using VR to study the heart compared to a traditional teaching method. Amongst the several cells, tissues and organs of the human body, the heart was chosen as the focus of this study because it is a very challenging topic to teach and to understand due to its complex 3D nature. Some modes of anatomy learning such as text books, medical imaging, and cadaver use have some drawbacks in explicitly displaying the true 3D nature of the heart. But through VR, a computer generated 3D heart model in an immersive, interactive virtual environment can be studied anywhere, other than the classroom. The VR aspect incorporated the use of predesigned software on Steam. Sharecare YOU VR was purchased for this purpose. The non-VR aspect used PowerPoint presentation as the traditional learning method. PowerPoint was used to avoid knowledge transfer bias between the 2 learning methods because the intended advantage in this study for the VR participants' was an immersive and interactive 3D heart model; normal and abnormal. Students mainly from the graduate biomedical engineering program were recruited to help prove if studying with VR produces significant and better results or not compared to other traditional methods. Biomedical engineers design and develop medical devices for improving human health. The heart is no exception because several devices can be found on the medical market for the heart so basic knowledge of the heart structure and how it functions are important. These students had the task of studying the heart with either VR or a traditional method. Also to get measurable results, they also had to perform a quiz to assess their knowledge prior to the study as well as their knowledge after the heart lessons. To be able to discuss the expected results, the following research questions guided this study to reach the goal:

1. Are the quiz scores improved after intervention in both groups?
2. Are the quiz scores more improved using VR education as compared to the other non-VR teaching method? If yes, is it statistically significant?
3. Is VR a more effective way to improve learner's level of cardiac anatomy knowledge?
4. Do factors like gender and age have an effect on the student's performance?
5. Is the students' perceived learning and effectiveness of using VR for cardiac anatomy education a positive, negative or neutral experience?

It can also be concluded finally that if such an application is useful for biomedical applications.

The COVID 19 lockdown with school closure presented some threats to this thesis. Accessibility to the school laboratories was limited. Education, particularly medical education came to a halt with emergent measures put in place to restore it. E-learning became the sort after remedy to curb this problem. This study also faced some threats due to the on-going Covid situation. Stringent rules were put in place for the study to be carried out to ensure safety; hence 1 or 2 participants could be present at the same time in the laboratory. Proof of negative COVID-19 test was also required to be able to access the laboratories at a period during the data collection phase.

5 Materials and Methods

5.1 Participants

Forty students from Hochschule Anhalt participated in this study. 90% of the students were graduate biomedical engineering students. They were targeted for this study because they have low to medium anatomy knowledge and biological background, even though they have medical subjects amongst their courses. Participants have no neurological, mental or visual abnormalities. Neither did they consume alcohol 12 h before the study. All these were identified by a self-data questionnaire. All participants were volunteers, older than 18 years old and received no compensation for their participation.

5.2 Learning Methods

Two learning methods were used. Participants were randomly allocated into an experimental (VR) or a control (Non-VR) group, 20 in each group to study the heart. The VR group studied educational material using high-immersive VR from Sharecare You VR application on Steam as shown in Figure 19 and 20. This software was used because it provides accurate unique cardiac virtual environment that has 3D heart content and videos including anatomy, physiology, conditions, and treatments, informative labels and contextual information with voice-over pronunciation and interactive tools and functionality to dissect, handle, customize and explore the heart in 360 degrees. It is also compatible with all major VR headsets with minimum computer requirements [163]. The control group, PowerPoint group, studied the heart with a PowerPoint presentation, containing similar educational texts taken from the Sharecare You VR application but with 2D and 3D images of the heart. The content of the learning materials for both groups was an overview of the human heart, heart exterior and interior especially the heart chambers and valves, heart blood circulation, heart conduction system and a few abnormal heart anatomies such as, coronary artery disease, heart failure, aortic stenosis.

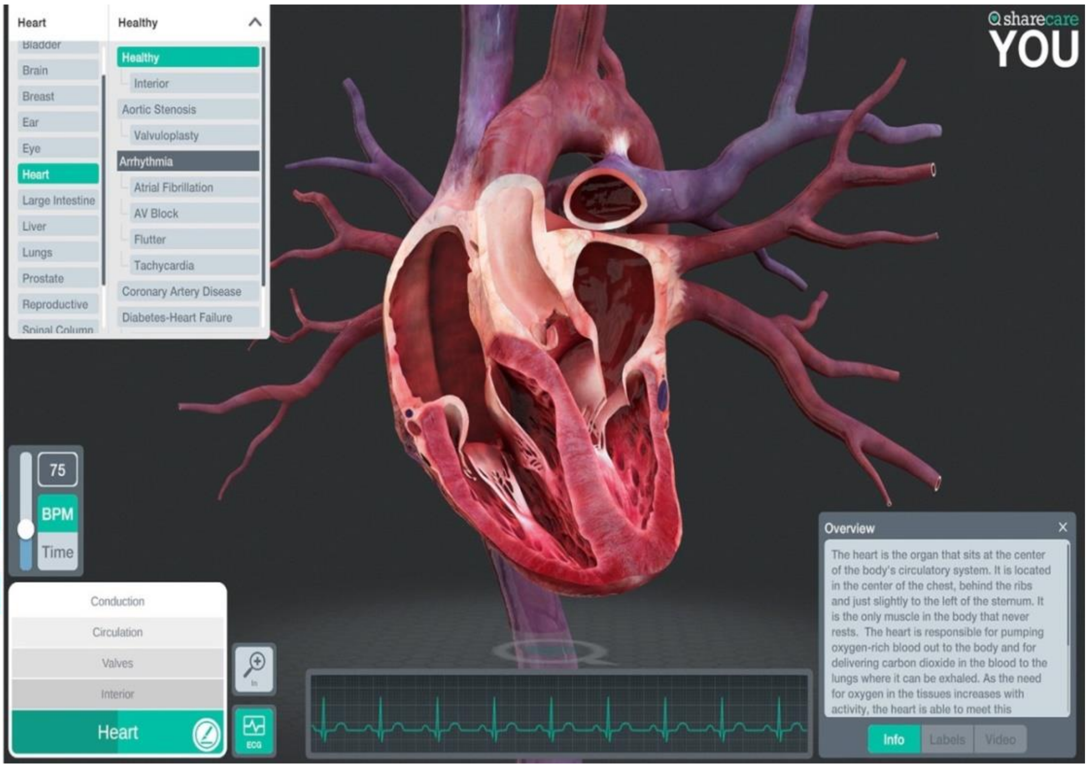

Figure 19 : Sharecare YOU VR Software - Virtually Dissected Heart [163]

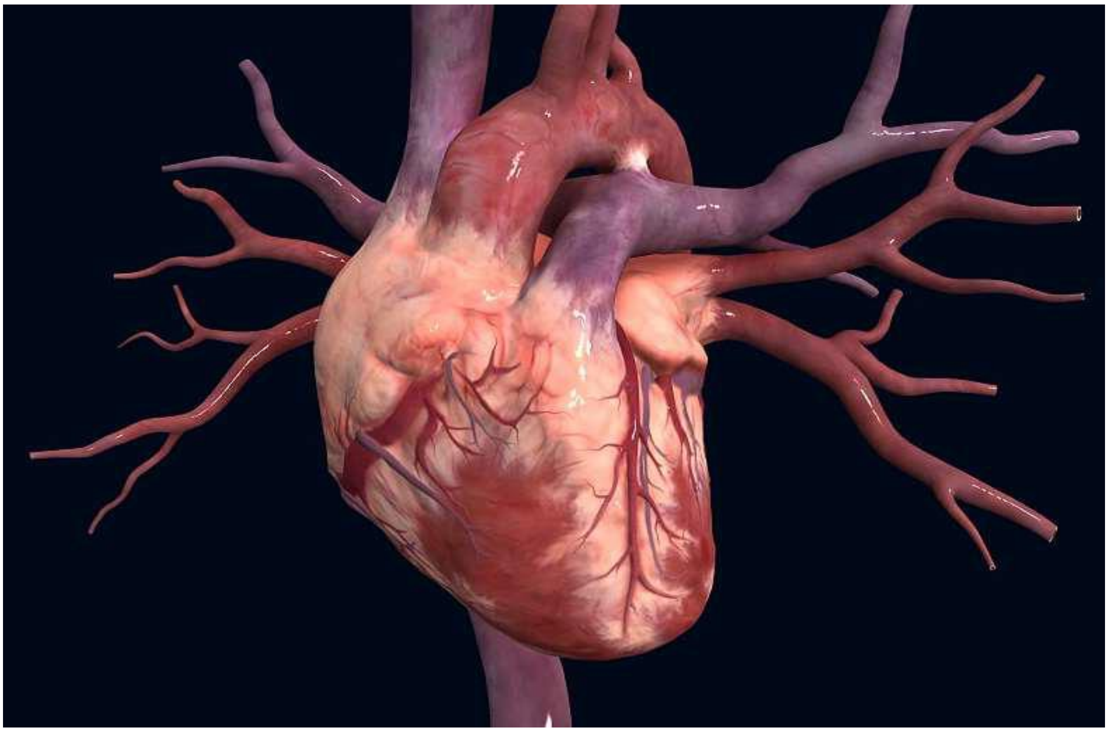

Figure 20 :Sharecare YOU VR - “Outside View” of the Heart as Seen in VR [163]

Contents from both learning methods,VR and Non-VR group, were verified for anatomic correctness and relevance by an expert surgeon with several years of medical experience after seeking feedback before the materials was used. Appendix 2 and 3 show the learning material used in the VR and Non-VR group respectively.

5.3 Apparatus

For comfortable use of VR HMD, a computer with an Intel Core i7-6700 CPU, 16GB RAM , an NVIDIA GeForce GTX 1080 GPU and a windows 10 (64-bit) operating system are the minimum requirements for use with the Varjo VR-2 HMD [164]. However the computer used had specifications of an Intel Core i7-8700 CPU, 64GB RAM, an NVIDIA GeForce RTX 2080 GPU and a windows 10 (64-bit) operating system.

Varjo VR2 advanced 20/20 Eye Tracker™ technology is equivalent to the human eye vision with a bionic display , refresh rate of 90 Hz, dual 1920 x 1080 resolution micro-OLEDs, dual 1440 x 1600 resolution AMOLEDs, and 87°horizontal field of view [165]. In 2019, the VR-2 became the world's only VR headset with human eye resolution (3,000 ppi). With Bionic Display™ renders and simulations come to life in VR with never-before-seen clarity. Every detail, texture, contour and colour are all just as crisp and clear as they are in the real world. You can read the smallest text and see objects at a distance And real-time illumination appears just as it does in the real world [166]. Varjo VR-2 was used because I wanted the students to have a natural user experience with a headset that mimics the human eye while visualizing the 3D heart model. It also offers the most advanced eye tracking technology of which the data generated can be used for further studies.

Varjo VR-2 supports SteamVR tracking hence two base stations were set up in order to track the headset and the controllers. Two HTC Vive controllers were used for interacting and navigation.

Figure 21 : Varjo VR-2 [164]

Figure 22 : User Wearing VR Equipment and Required Setup

5.4 Knowledge Assessment

Both experimental and control group participants completed a pre- and post- intervention quiz (Appendix 1), consisting of twenty multiple choice questions : 11 conventional,non-visual spatial and 9 visual-spatial cardiac anatomy questions.

Quiz questions and answers used for this study was verified for accuracy and relevance by an expert surgeon.

5.5 Procedure

Upon arrival at the laboratory, the participants, who came willingly with no compensation received, completed a demographic survey and the pre-intervention quiz to test their baseline knowledge of the heart. Then a 20-30 minutes learning session took place using either VR or PowerPoint learning modes. The learning materials were identical in content.

As seen in figure 23,all students who were exposed to the VR experience were outfitted with Varjo VR-2 headset (developed and manufactured by Varjo, released on October 15, 2019) and HTC Vive controllers.They were subsequently given a five minute tutorial on VR device familiarization, how to view and interact with the VR platform, and how to use the controllers to manipulate other organs on the software, for example liver, in three dimensions. This included explanations of how to toggle between different views and menus in order for them to easily and uninterruptedly interact with the 3D heart model from the Sharecare YOU VR application. The operator intervened only if a participant requested clarification or assistance.

Figure 23 : VR Group Students Learning the Heart

The students in the control group were exposed to a conventional way of studting the heart thus with PowerPoint presentation delivered by the same operator as illustrated in figure 24.

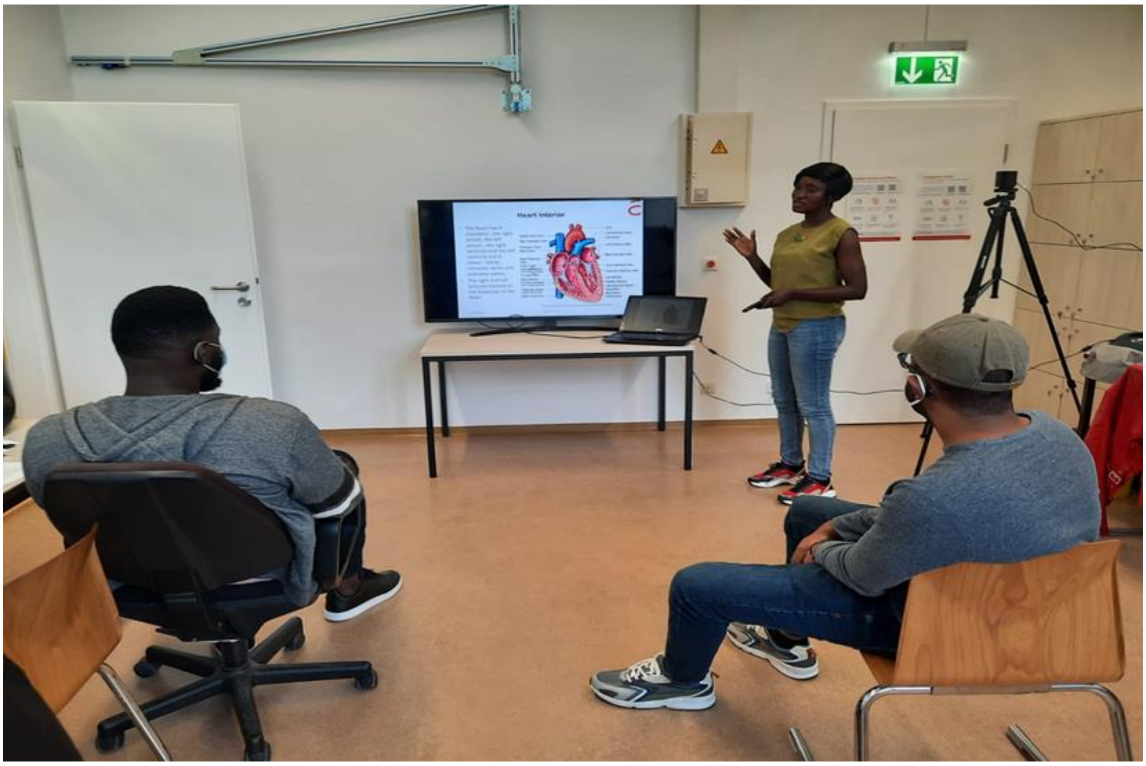

Figure 24 : Non-VR Group Students Learning the Heart with PowerPoint

At the end of the intervention, both groups were immediately subjected to a second,post-intervention, quiz (same 20 questions) to test their knowledge of the heart again.

Also a subjective questionnaire was administered to only the experimental,VR, group about their experience and degree of satisfaction with using VR to study the heart.This was to evaluate students' perceived learning and the effectiveness of VR. It was done to obtain and assess the participants thoughts and opinions on VR implementation in the study of the heart. Appendix 4 contains the questionnaire used.

Following the completion of the data collection, participants from the Powerpoint,Non-VR group were invited to experience the same VR simulation as their peers in the experimental group. Duration of the complete study was 75 – 90 minutes. Some students in the VR group complained of eye fatigue after the exposure.

5.6 Statistical analysis

The number of correct answers prior and post learning session, expressed as a percentage of the total number of questions, were calculated. The between individual factor was the two groups of participants (PowerPoint, VR) and the within individual factor was the two time points (pre-versus post educational session). Evaluation of differences in mean scores between the groups and assessment of the statistical significance of the differences in the mean scores of the test before and after the learning session within and between the groups was done using paired sample student t-test. The statistical significance, p value within and between the groups as well as the Z value was evaluated using Wilcoxon Signed Rank test. Pearson Correlation coefficient, r , was calculated within both groups to assess the association between the pre- and post -intervention scores as well as the self-reported prior cardiac anatomy knowledge and the pre-intervention quiz scores. Chi square tests were used for the demographics; age, gender, prior cardiac anatomy knowledge and prior VR experience within and between the two groups. Nonparametric independent sample test was performed within the groups to ensure that post-intervention quiz scores did not significantly differ regarding the demographic; age and gender. All the results have been normalised by 100 thus the values are between 0 and 100. The significance level (Sig. / p) for all analyses was 0.05. All data analyses were performed in Matlab R2021a and IBM SPSS Statistics 28.0 software.

6 Results

According to the demographic survey, out of the 40 enrolled students in the study, 23 (57.5%) were male and 17 (42.5%) female and their ages ranged from 21 – 35 years, with the majority (82.5%) between the ages 26 – 30 years. 23 (57.5%) participants answered having no to low cardiac anatomy knowledge, 16 (40%) responded to having medium cardiac knowledge and 1 (5%) responded to having high knowledge in cardiac anatomy. Seventeen (42.5%) of the participants had never tried VR prior to this experiment, twenty (50%) rarely used VR, two (5%) used on a weekly basis and only one (2.5%) participant used it on a daily basis. However, none of the participants had the experience of using VR to learn anatomy. No significant differences were observed regarding the demographics; age, gender, responded prior cardiac knowledge and prior VR experience between the groups.

Table 1 illustrates full demographic data of the participants.

	VR Group	Non-VR Group	Total	P (VR vs. Non-VR)
N	20	20	40	
Gender, n (%)				
Male	11(55)	12(60)		
Female	9(45)	8(40)		
P	0.655	0.371	0.343	0.157
Age, n (%)				
21 – 25	3(15)	2(10)		
26 – 30	17(85)	16(80)		
31 – 35	0	2(10)		
P	0.002	< 0.001	< 0.001	0.223
Reported prior cardiac knowledge, n (%)				
Low	12(60)	11(55)		
Medium	7(35)	9(45)		
High	1(5)	0(0)		
P	0.011	0.655	< 0.001	0.199
Reported prior VR experience, n (%)				
None	11(55)	6(30)		
Yes- Daily	0(0)	1(5)		
Yes-Weekly	1(5)	1(5)		
Yes – Rarely	8(40)	12(60)		
P	0.019	< 0.001	< 0.001	0.238

Table 1 : Demographic Survey

For the knowledge assessment, the number of correct answers prior and post learning session, expressed as a percentage of the total number of questions, were calculated. On the pre-intervention quiz, the students scored on average 51.5% (SD = 17.85) in PPT group and 47 % (SD = 20.55) in VR group content. On the post-intervention quiz, the students scored on average 76.75 % (SD = 11.73) on PowerPoint content and 81.75% (SD = 9.64) on VS content. Both group demonstrated an overall significant increase in post-intervention quiz scores. The control group demonstrated a (25.25 %, $p < 0.001$), while the experimental group participants demonstrated a (34.75%, $p < 0.001$.) On the post-intervention quiz between the experimental and control group, the students exposed to VR scored on average 5% ($p = 0.12$) higher than the students exposed to the conventional content, PPT. In terms of visual spatial skills that comprised of 9 questions in the quiz, 13 (65%) students out of 20 in the VR group had a perfect score, compared to the control PowerPoint group where 5 students (25%) out of 20 had a perfect score in the post-intervention quiz ($p = 0.107$). It was observed that, participants took shorter duration to complete the post intervention quiz but the time was not recorded. Some students in the VR group complained of eye fatigue after the exposure. Illustrated below : Table 2 and Figure 25 depict results for control or Non-VR group, Table 3 and Figure 26 depict results for experimental or VR group, and Table 4 and Figure 27 depict summary results for both groups.

	Minimum score	Maximum score	Mean	Standard Deviation	Standard Error Mean	Pearson Correlation	P	Z
Pre-Intervention	10	75	51.50	17.85	3.992			
Post-Intervention	55	95	76.75	11.73	2.623			
Pre- and Post-Intervention			25.25	17.36	3.881	0.37 Sig.= 0.108	< 0.001	-3.630
Age and post-intervention							0.045	
Gender and post-intervention							0.785	
Cardiac knowledge and pre-intervention						0.471 Sig.= 0.036		

Table 2 : Summary of Non-VR Group's Results

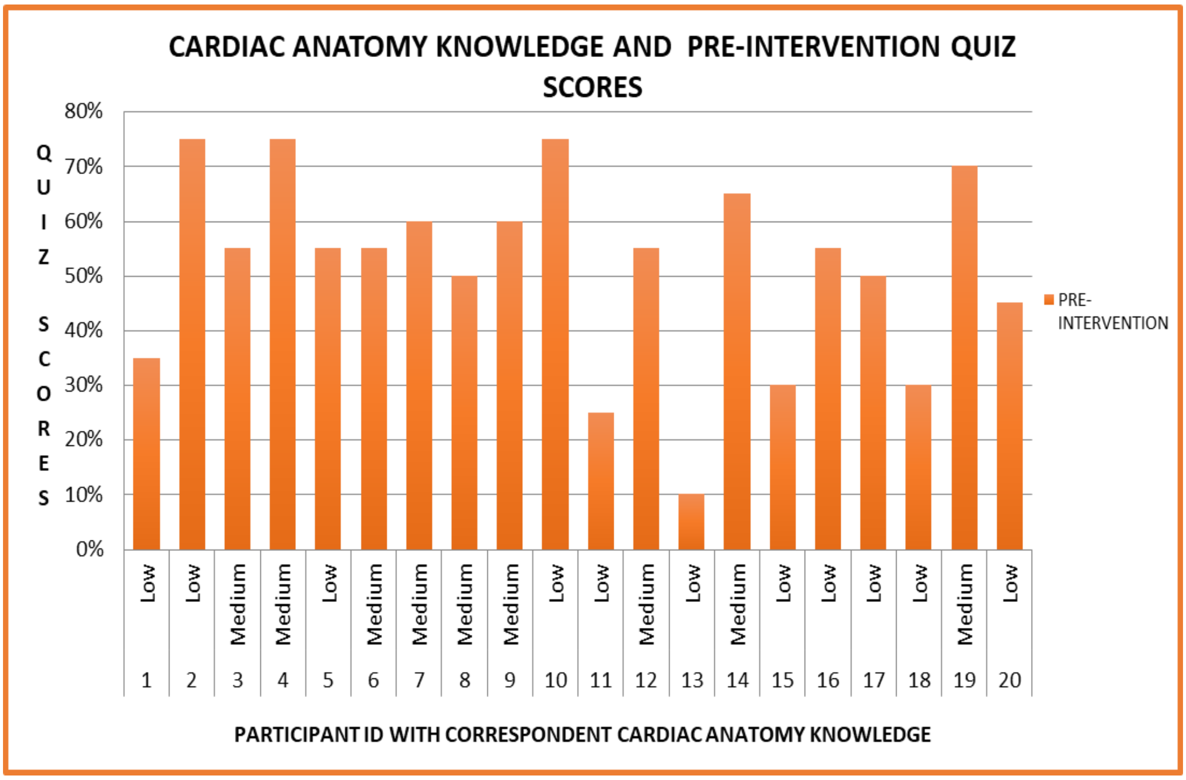

Figure 25 : Chart Showing Cardiac Knowledge Response and Pre-Intervention Quiz Scores

	Minimum score	Maximum score	Mean	Standard Deviation	Standard Error Mean	Pearson Correlation	P	Z
Pre-Intervention	5	90	47	20.55	4.59			
Post-Intervention	60	100	81.75	9.64	2.15			
Pre- and Post-Intervention			34.75	19.09	4.27	0.38 Sig.= 0.098	< 0.001	-3.927
Age and post-intervention							0.386	
Gender and post-intervention							0.087	
Cardiac knowledge and pre-intervention						0.686 Sig. < .001		

Table 3 : Summary of VR Group’s Results

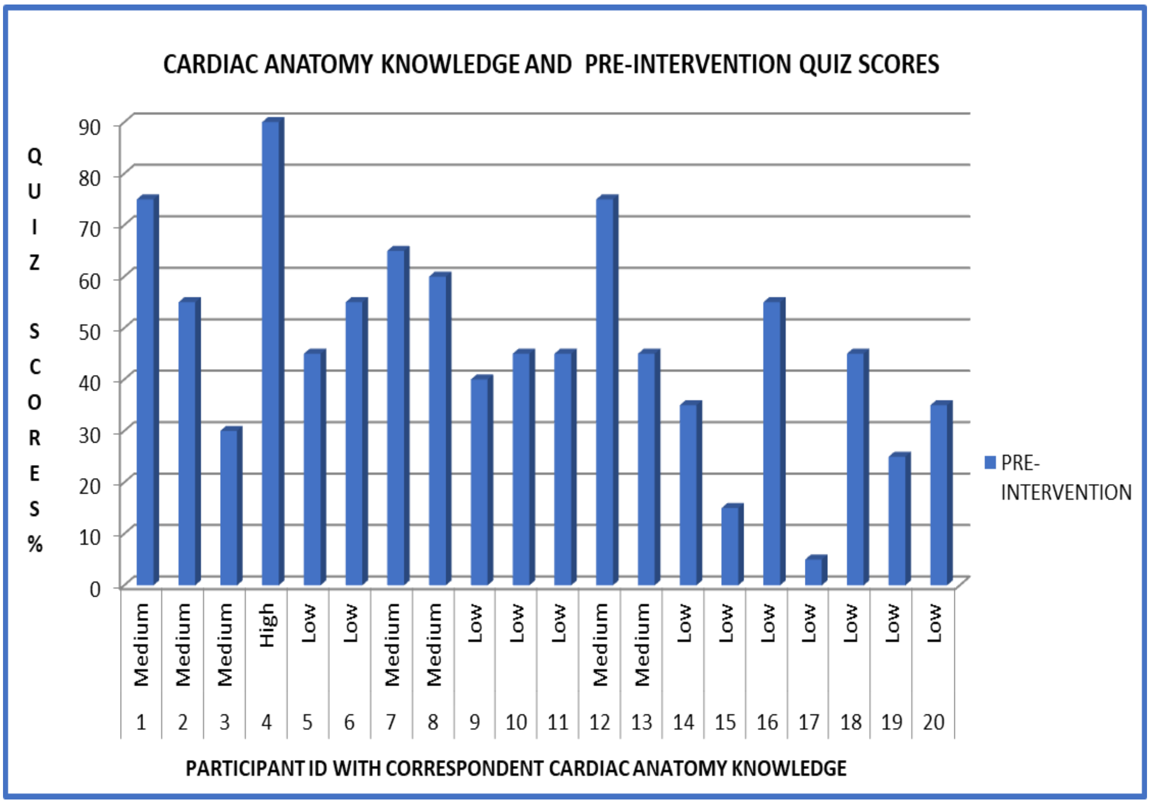

Figure 26 : Chart Showing Cardiac Knowledge Response and Pre-Intervention Quiz Scores

	Non-VR Group Pre-Intervention vs. Post Intervention Results	VR Group Pre-Intervention vs. Post Intervention Results	Non-VR Group Post Intervention vs. VR Group Post Intervention Results
Mean difference	25.25	34.75	5
Z	3.630	3.927	- 1.557
Significance level	P < .001	P < .001	P= 0.12

Table 4 : Summary of Test Results between Both Groups

The figure below shows “bars: mean” (the grey) and “standard deviation” (orange line). The horizontal axis represents the pre- and intervention results in both groups. 1 and 2 represent the pre- and post-intervention mean value in the non-VR group respectively as 3 and 4 represent VR pre- and post-intervention mean value respectively. All show the correspondent standard deviation. The vertical axis represents the mean scale between 0 and 100 with 0 being the lowest value and 100 being the highest value.

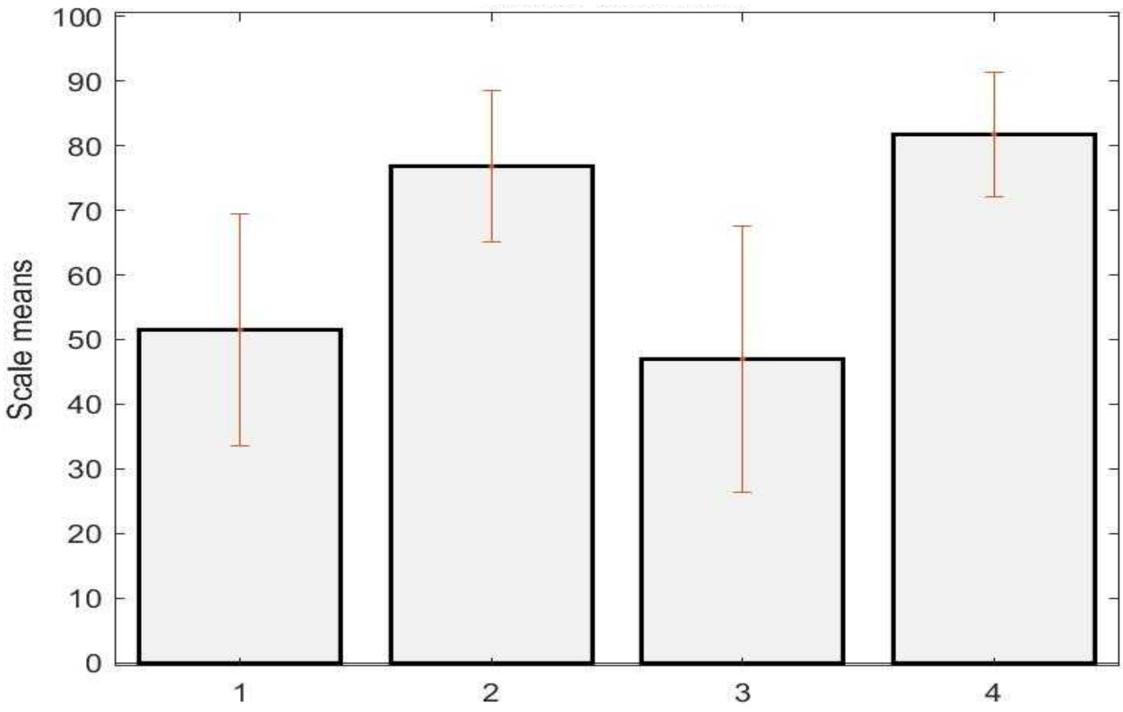

Figure 27 : Bar Chart with Error Bars Illustrating Result Summary In Both Groups

The subjective questionnaire performed in the experimental (VR) group was done to measure the degree of satisfaction and students’ perceived learning and effectiveness of using VR to study the heart. All the 20 participants returned the questionnaire on perceived learning and effectiveness of VR. Eleven (55%) students had never tried VR prior to this experiment, nine (45%) rarely used and only one (5%) used VR on a weekly basis but none used it for anatomy learning. Nineteen students (95%) agreed or strongly agreed that “seeing the heart from the inside reinforced my knowledge of cardiac anatomy”, that “the anatomic relationship between different structures in the heart is easily seen in Cardiac VR”. Five students (25%) strongly agreed and 15 students (75%) strongly agreed that “Cardiac VR enhances anatomic integration skills”, however 10 students (50%) strongly agreed, 9 students (45%) agreed and 1 student (5%) disagreed with the statement that “Cardiac VR can improve visual-spatial skills. Eleven students (55%) strongly agreed and nine students (45%) strongly agreed that “Cardiac VR provides useful 3D interaction and I enjoy it”. To the statement “Cardiac VR assisted me in appreciating size differences of different structures”, fourteen (70%) strongly agreed and six (30%) agreed. “Cardiac VR is useful for my learning”, eight (40%) strongly agreed, nine (45%) agreed and three (15%) somewhat agreed. To the statement “I enjoyed Cardiac VR” sixteen (80%) strongly agreed, three (15%) agreed and one (5%) somewhat agreed. To the statement “I learn more when I have fun” five (25%) strongly agreed, 9 (45%) agreed and six (30%) somewhat agreed. Sixteen (80%) strongly agreed, three (15%) agreed and one (5%) somewhat agreed with the statement

“I like the idea of VR and would like to see more of it in my education.” No student strongly disagreed with any statement.

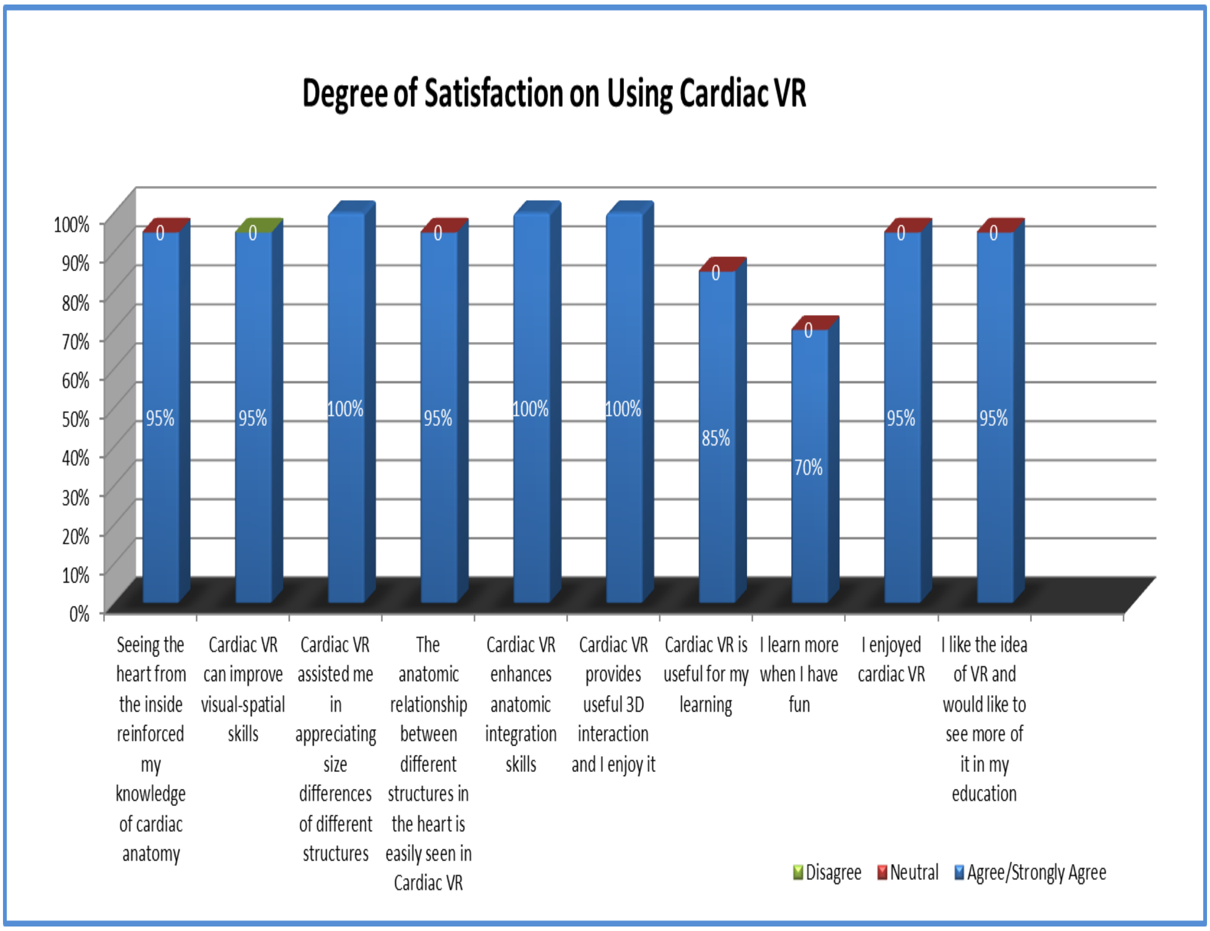

Figure 28 : Subjective Questionnaire in the Experimental (VR) Group

7 Discussion

Within the field of medical education, the use of VR has been validated as an effective way to improve the learners’ level of anatomy knowledge and previous research has demonstrated the utility of 3-dimensional learning with evidence relating to medical education, particularly in the cardiovascular system [167] [2]. Hence the objective of this study to assess the educational effectiveness of using VR to study the heart compared to a conventional approach. To achieve this, two different learning methods – a conventional approach with PowerPoint presentation and an immersive VR 3D cardiac model approach. The study incorporates the use of the Varjo VR-2 HMD system to provide a completely immersive experience of a 3D heart model with human eye resolution.

In general, it was found that, no significant differences existed in age groups ($p = 0.223$) and gender ($p = 0.157$) between the two groups even though a study by Alan Bleakley mentions that gender is an important factor influencing teaching effect [168] .

In the experimental group, the average pre-intervention score was 47 % with an average score increment of 34.75 % to reach an average of 81.75% at the post-intervention scores ($Z = 3.927$, $p < 0.001$). This finding indicate that there was statistically significant difference in quiz scores after the intervention hence the VR simulation was an effective way of increasing the learners' level of heart anatomy knowledge. All the participants had increment on the post-intervention quiz. Neither age range ($p = 0.386$) nor gender ($p = 0.087$) had any difference had an impact on the post-intervention quiz scores. In terms of Pearson correlation coefficient, the relationship ($r = 0.38$, $p = 0.098$) between the pre-intervention and post intervention quiz scores show a weak and positive correlation However, this positive correlation is statistically not significant. Also the relationship ($r = 0.686$, $p < 0.001$) between the students' responded prior cardiac anatomy knowledge and their performance on the pre-intervention quiz scores show statistically significant moderate positive correlation. This implies that their responses on prior cardiac knowledge truly reflected on their pre-intervention quiz performance.

In the control group, the average pre-intervention score was 51.50% with an average score increment of 25.25 % to reach an average of 76.75% at the post-intervention scores ($Z = -3.630$, $p < 0.001$). This indicate that there was statistically significant difference in quiz scores after the intervention hence the PowerPoint presentation was also an effective way of increasing the learners' level of heart anatomy knowledge. Three students scored same on pre- and post-intervention quiz. Gender ($p = 0.785$) had no significant difference on the post-intervention quiz scores, however age ($p = 0.045$) rejected the null hypothesis of equal quiz scores across the age groups. This could imply that, there was a tendency of age being an influencing factor in this group's performance on the post-intervention quiz. In terms of Pearson correlation coefficient, the relationship ($r = 0.37$, $p = 0.108$) between the pre-intervention and post intervention quiz scores show a weak and positive correlation However, this positive correlation is statistically not significant. Also the relationship ($r = 0.471$, $p = 0.036$) between the students' responded prior cardiac anatomy knowledge and their performance on the pre-intervention quiz scores show weak to moderate positive correlation but not statistically significant. This implies that their even though a correlation existed between their responses on prior knowledge and pre-intervention quiz score, it may not have necessarily reflected on their performance.

Between the control and experimental group, the mean increment was 5% ($Z = -1.557$, $p= 0.12$) .This indicate that there was no statistically significant difference of anatomy knowledge gain in the post-intervention quiz between the 2 groups even though on average the VR group scored 5% higher than the PowerPoint group. A larger number of participants might show a significant result. The negative z values recorded within and between both groups indicate that the raw data value was a number of standard deviation times below the mean value: 3.630 in Non-VR group, 3.927 in VR group and 1.557 between the groups.

Overall, no student retrogressed and scored lower on the post-intervention quiz in both groups. The students who gained the most information were those who had a low baseline level of the relevant knowledge, especially seen in the experimental group. That participant in the VR group exhibited a 65% knowledge increment from 35% on the pre-intervention quiz to 100% on the post-intervention quiz. It was observed that, the VR participants took shorter duration to complete the post intervention quiz as compared to the non-VR participants but the time was not recorded.

The subjective questionnaire [1] performed on the experimental group to ascertain the degree of satisfaction as a secondary outcome for this study was positive. This was done to evaluate the students' perceived learning and effectiveness of using VR to study the heart. 95 – 100% of the students agreed or strongly agreed to the 8 out of the 10 statements posed in Appendix 4. Apart from the issues associated with the acquisition, storage, and disposal of potentially bio hazardous tissue specimens, another advantage VR has over cadaveric dissection is the ability to cut back or "clip" the three-dimensional model in a variety of planes, and then reassemble the anatomic model once virtually clipped. An essential lesson that can be gained from VR is to appreciate the relative size and proximity of distinct heart structures. The typical anatomic relationships of heart chamber interiors are distorted after dissection. In medical education, physically interacting with a three-dimensional model is critical for comprehending its physical build and gaining a sense of confidence and familiarity with it. This is certainly relevant for medical students studying anatomy or surgery [169] [170].

The VR students who took part in the study overwhelmingly appreciated the ability to dissect and resect an anatomically realistic heart in VR, appreciated the anatomic relationships and relative sizes between heart structures, as well as enjoyed cardiac VR and the useful 3D interaction it offered. Cardiac VR improves visual-spatial skills statement was clearly evident in the post-intervention quiz scores when 13 out of 20 VR group students had a perfect score compared to just 5 of their peers in the PowerPoint group. The 2 exceptions were statements “I learn more when I have fun” and “Cardiac VR is useful for my learning”, where 30% and 15% of the students respectively were neutral and somewhat agreed. Despite the aforementioned exceptions, 95% of the students agreed or strongly to the statement “I like the idea of VR and would like to see more of it in my education”.

In summary, these results indicate that VR was as efficient as the traditional method of learning from a PowerPoint presentation to study the heart. This study’s insignificant but positive results was rather found significant by other studies when using the VR to study the heart [1] [10] [15] but support a study where VR was applied in the study of the brain [162].

Furthermore, the overall results with the significant knowledge gain after the intervention within the groups could justify the fact that the participants had low to medium heart anatomy knowledge and the general need for graduate biomedical engineering students to have anatomy instruction in their study. This was also a fact established in Mayo graduate school [171] .

However some limitations could have led to the unexpected shortcomings of the study, particularly the small sample size. A higher number of students would have further supported the study’s goal of VR being more effective than traditional methods of learning anatomy. An indirect possible weakness of the study could have resulted for some students acting under stress while completing the task and not motivated enough due to the no compensation scheme for participation.

Also, data of the advanced integrated eye tracking technology of the Varjo VR-2 is been implemented in another research work titled ‘Analysis of Eye-Tracking Data in VR’. This study aims to correlate the VR quiz scores, pre- and post-, to the eye calibrated data generated from the VR intervention learning session of the heart.

8 Conclusion

This study demonstrated that VR was as effective as the traditional PowerPoint presentation in teaching cardiac anatomy in terms of students’ quiz scores, , yielding a performance increase of 5% in the experimental group over the control group. It also demonstrated a positive VR learner experience and enhanced student motivation. This was evident in in several subjective measurements: engagement, enjoyment, usefulness, and learner motivation.

While cardiac anatomy can be difficult to grasp due to its complicated three-dimensional form, VR provides an immersive and intuitive experience that allows users to appreciate the size variations between distinct heart structures as well as contextualize the links between them. Despite the apparent high cost of procuring VR hardware and software for medical institutions, VR has gained popularity in medical education, and this cost-benefit ratio may sway in the favour of VR. VR, when used in anatomically proper direction, has the potential to transform how normal and abnormal structural anatomy is taught.

Additional VR research in the field of cardiovascular medicine has showed promise in helping clinicians understand and comprehend images of cardiovascular anatomy and pathology more quickly, as well as perform cardiovascular therapies with more precision and less invasiveness [143].

Despite the fact that our results are encouraging, more research is required to establish the best and effective way to deliver this immersive content to students, alongside using a large sample size to undertake the task. Also cost-effectiveness and adverse reactions such as blurred vision and disorientation when evaluating the teaching effectiveness of VR in anatomy is also recommended.

Recent studies show that Virtual (VR), Augmented (AR), and Mixed-Reality (MR) can improve both retention and learning outcomes [135] hence further studies comparing the effectiveness of these three technologies should be investigated. Also an evaluation into incorporating both VR/AR into anatomy education is recommended.

In conclusion, VR technologies are improving in quality and becoming more widely available. As these trends continue, it will be easier to integrate virtual reality into anatomy classes and in medical training in general. Its usefulness in biomedical applications cannot be left out.

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Appendix

Appendix 1: Pre- and Post-Intervention Quiz Questions

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Cardiac anatomy quiz

Select the correct answer and attempt all questions

1. The right ventricle is the chamber of the heart that pumps blood for the pulmonary circulation. Based on this information, blood from the right ventricle is on its way to the ___________.
   a. Liver
   b. Lungs
   c. Right shoulder
   d. Right kidney

2. Which of the following is correct regarding the flow of blood in reference to the left side of the heart?
   a. Blood flows from the left atrium, through the bicuspid valve, into the left ventricle, through the aortic semilunar valve, and then into the aortic arch.
   b. Blood flows from the left atrium, through the aortic semilunar valve, into the left ventricle, through the bicuspid valve, and then into the aortic arch.
   c. Blood flows from the left atrium, through the bicuspid valve, into the left ventricle, into the aortic arch, through the aortic semilunar valve, and then into the pulmonary arterial system.
   d. Blood flows from the left atrium through the bicuspid valve, into the left ventricle, into the pulmonary trunk, through the pulmonary semilunar valve, and then into the pulmonary arteries.

3. The venae cavae empties blood into this cardiac chamber.
   a. Right atrium
   b. Right Ventricle
   c. Left atrium
   d. Left ventricle

4. During ventricular contraction, the atrioventricular valves close in order to
   a. Speed up the action potential as it moves through the conduction system.
   b. Prevent the backflow of blood from the ventricles to the atria.
   c. Enhance drainage of the coronary veins.
   d. Push blood into the venae cavae.

5. Stenosis of this valve causes left ventricular hypertrophy.
   a. Pulmonic
   b. Mitral
   c. Aortic
   d. Tricuspid

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6. Which of the following is not true about the left ventricle?
   a. Pumps blood into the aorta.
   b. Receives blood from the left atrium
   c. Contains oxygenated blood
   d. The oxygen from blood within the left ventricle diffuses across the endocardium into the left ventricular myocardium.

7. The heart is located in which anatomical subdivision of the mediastinum?
   a. Anterior
   b. Posterior
   c. Middle
   d. Superior

8. What area of the heart's electrical conduction is known as the "pacemaker" of the heart?
   a. SA node
   b. AV node
   c. Purkinje Fibres
   d. Bundle of HIS

9. The pulmonic and tricuspid valves are associated with this structure.
   a. Right atrium
   b. Right Ventricle
   c. Left atrium
   d. Left ventricle

10. These blood vessels arise at the base of the aorta just beyond the aortic valve.
   a. Pulmonary veins
   b. Pulmonary arteries
   c. Coronary veins
   d. Coronary arteries

11. Which of the following can be used to repair and/or replace a stenotic heart valve?
   a. Valvuloplasty
   b. Trans-aortic valve replacement
   c. Neither A or B
   d. Both A and B

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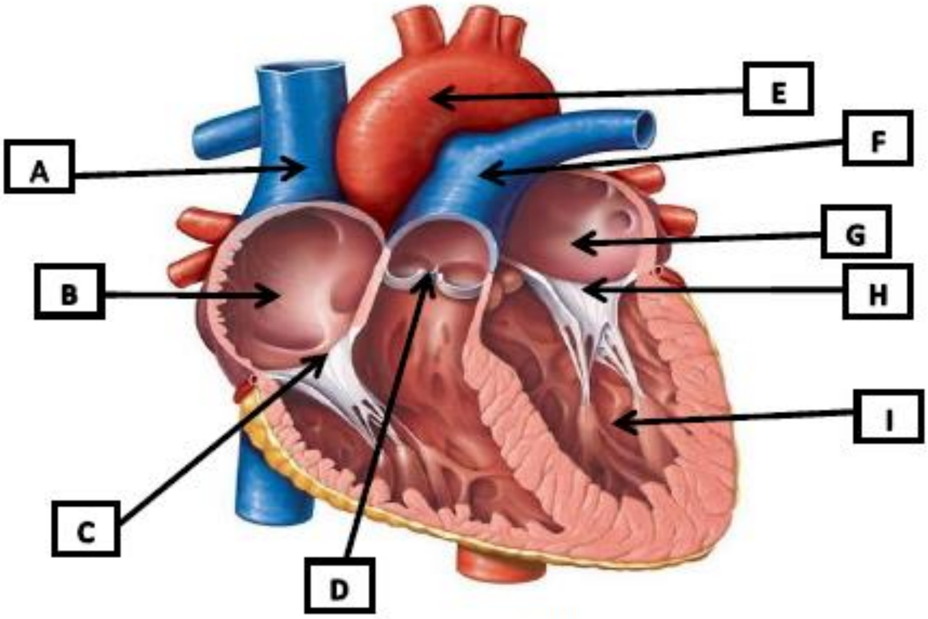

Figure 1

Using the diagram above, Figure 1, answer the following questions:

12. What structure is **E**
a. Aorta
b. Coronary artery
c. Superior vena cava
d. Inferior vena cava

13. What structure is **F**
a. Aorta
b. Pulmonary artery
c. Pulmonary vein
d. Coronary artery

14. What structure is **G**
a. Left atrium
b. Right atrium
c. Left ventricle
d. Right ventricle

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15. What structure is **C**
    a. Pulmonary valve
    b. Mitral valve
    c. Tricuspid valve
    d. Aortic valve

16. What structure is **A**
    a. Aorta
    b. Coronary artery
    c. Superior vena cava
    d. Inferior vena cava

17. What structure is **H**
    a. Aortic valve
    b. Pulmonic valve
    c. Mitral valve
    d. Tricuspid valve

18. What structure is **D**
    a. Aortic valve
    b. Pulmonic valve
    c. Mitral valve
    d. Tricuspid valve

19. What structure is **B**
    a. Left Atrium
    b. Right Atrium
    c. Left Ventricle
    d. Right Ventricle

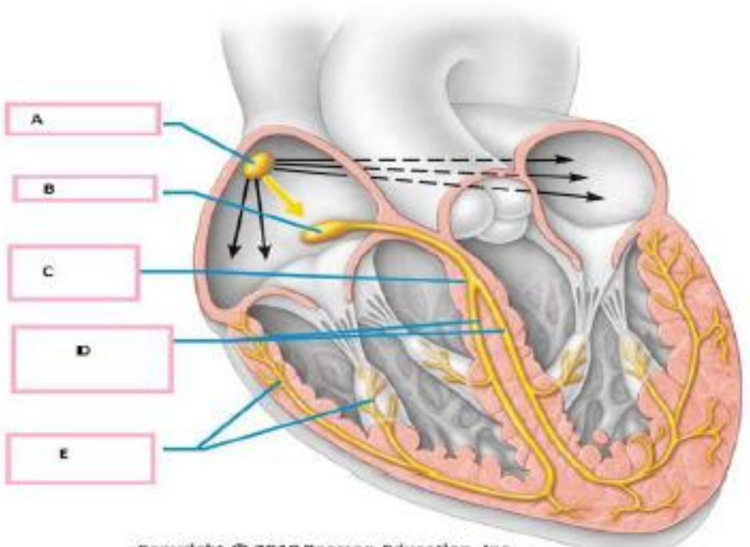


Figure 2

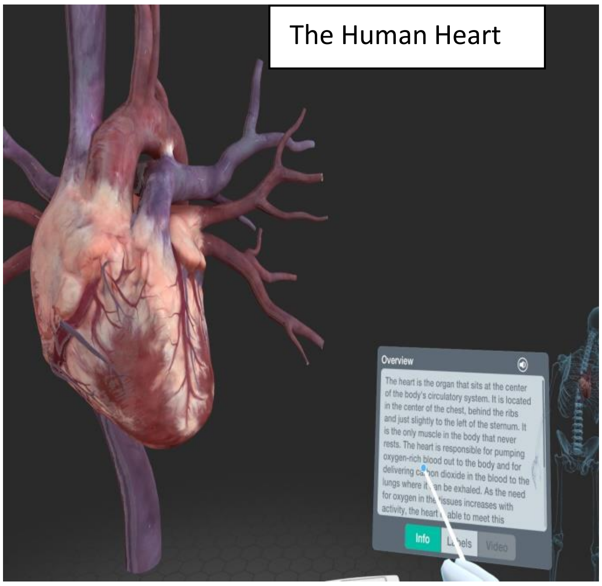
Using the diagram above,Figure 2

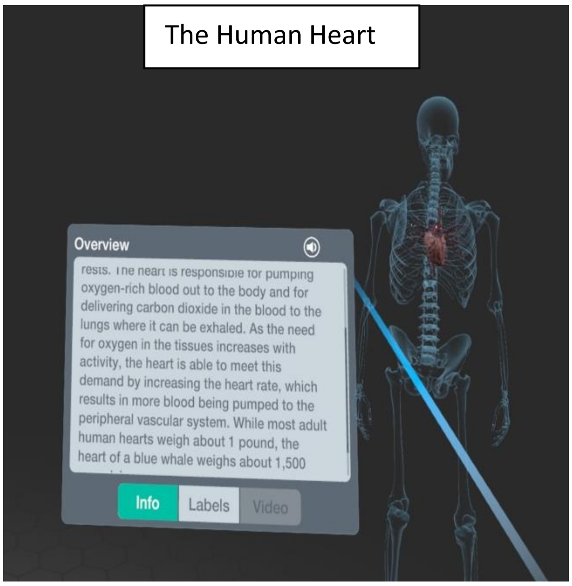
20. What structure is **B**
  a. SA node
  b. AV node
  c. Purkinje Fibres
  d. Bundle of His

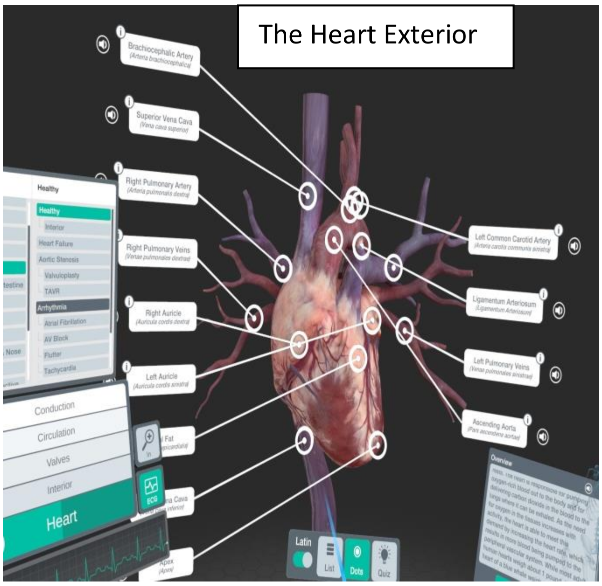
THE END.

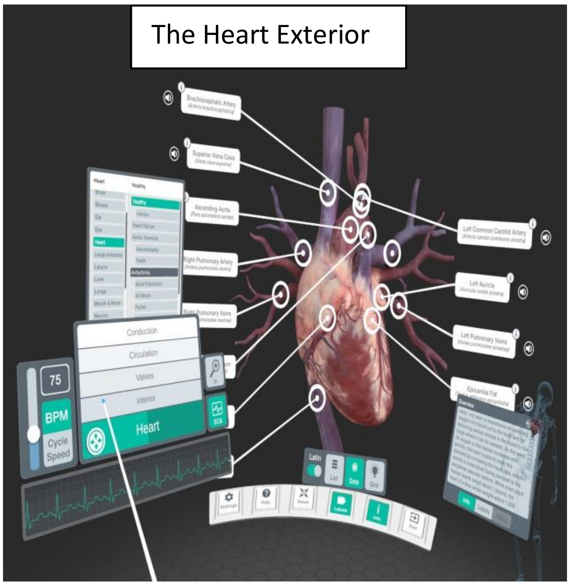
THANK YOU FOR YOUR PARTICIPATION.

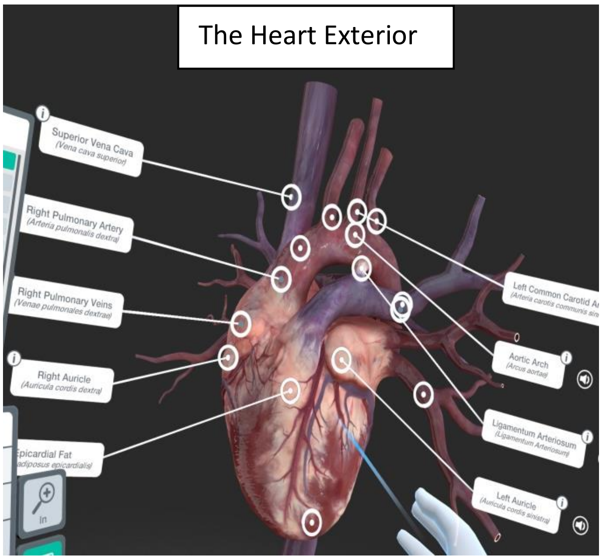
Appendix 2: Excerpts from Experimental Group (VR) Learning Material

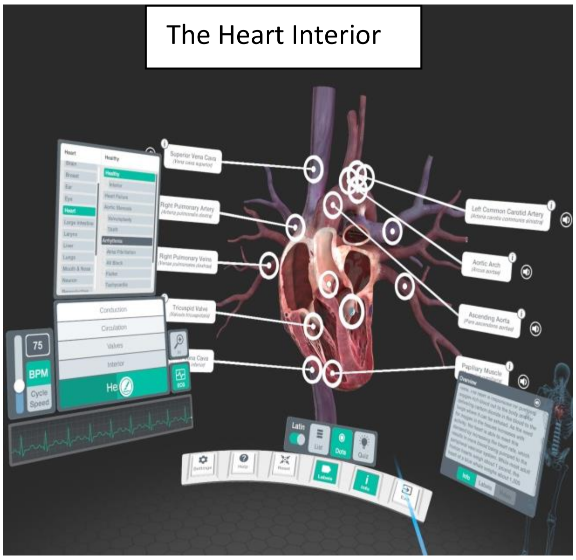


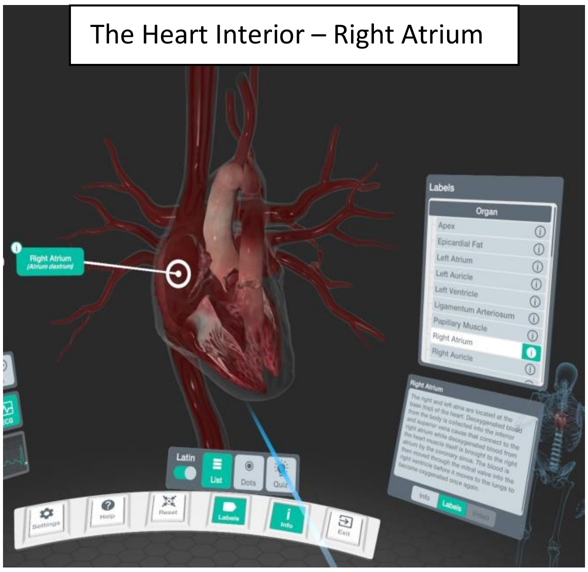


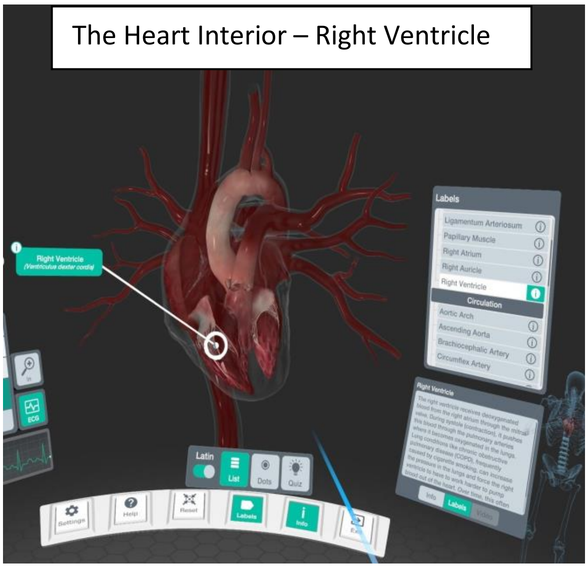


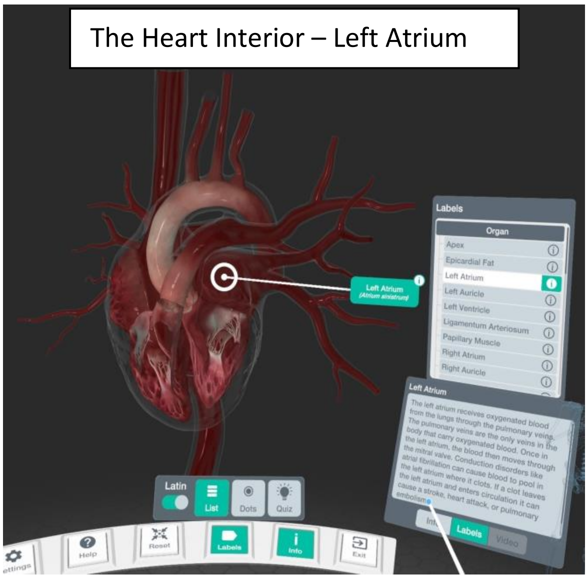


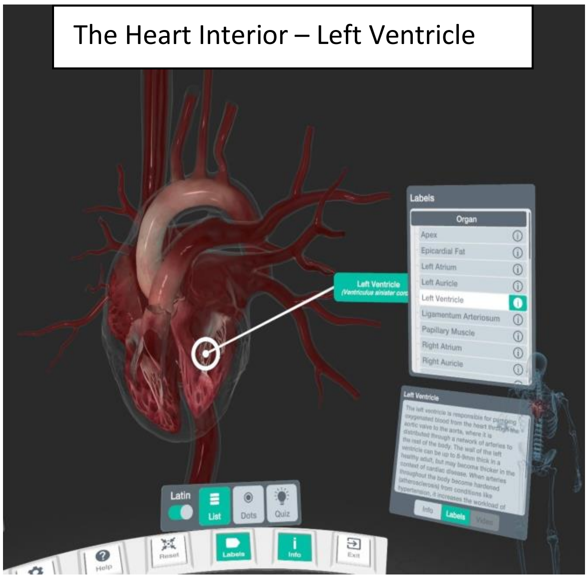


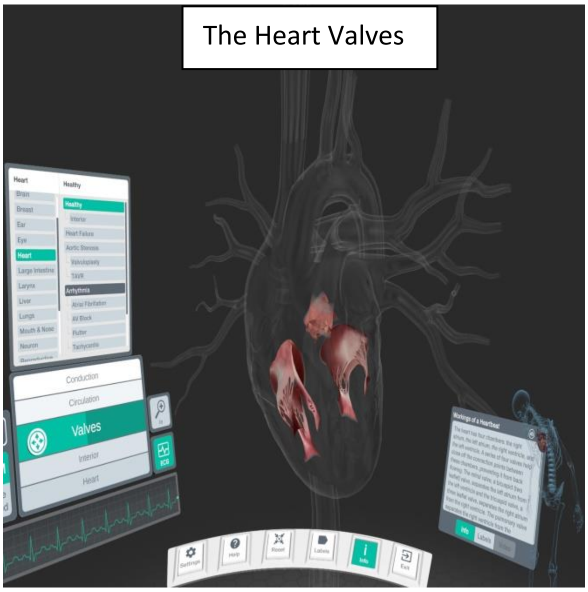


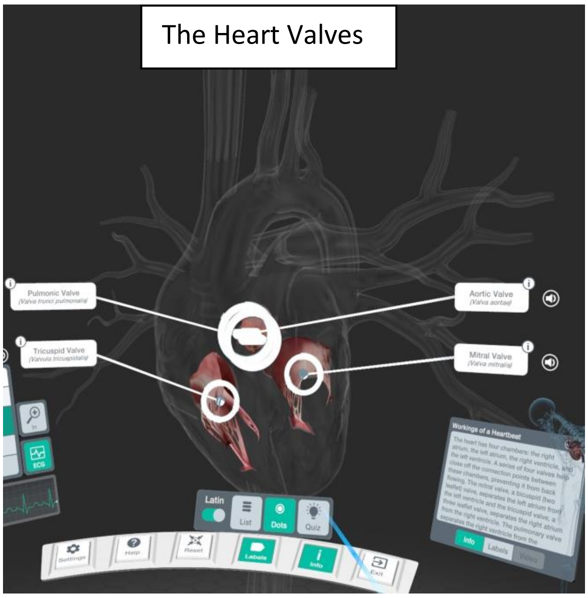

The Heart Interior – Right Atrium

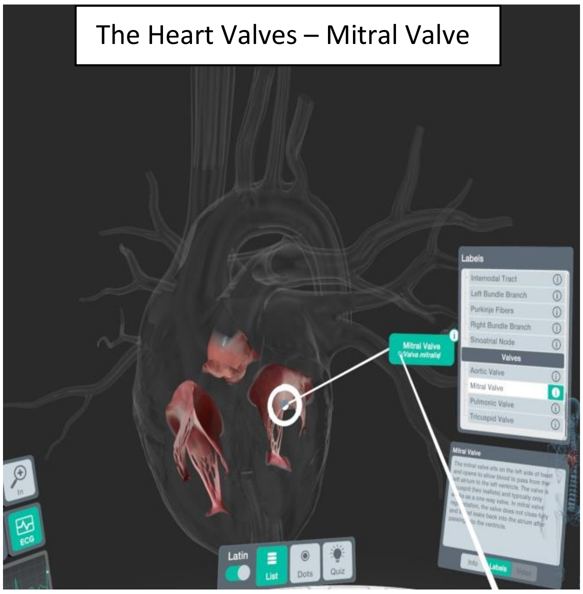

The Heart Interior – Right Ventricle


The Heart Interior – Left Atrium

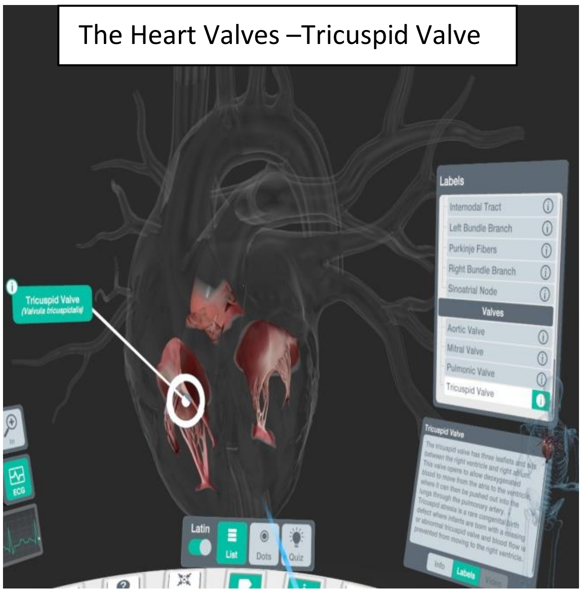

The Heart Interior – Left Ventricle


The Heart Valves

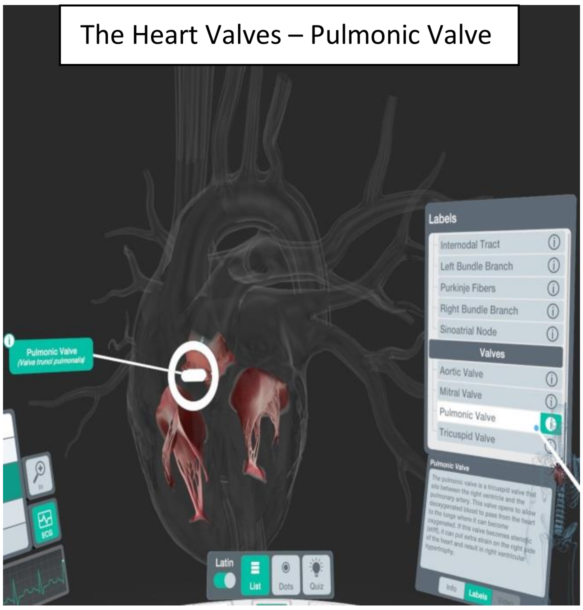

The Heart Valves



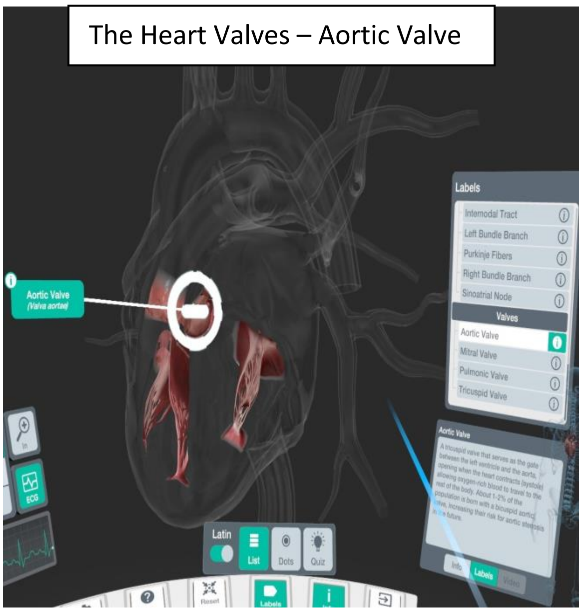
The Heart Valves – Mitral Valve



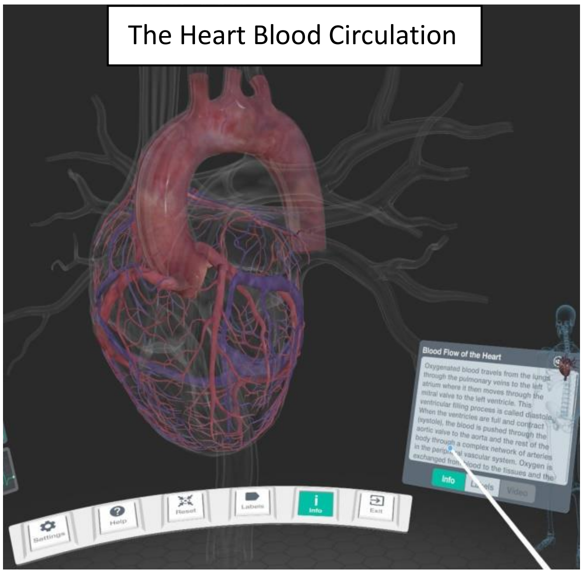
The Heart Valves –Tricuspid Valve



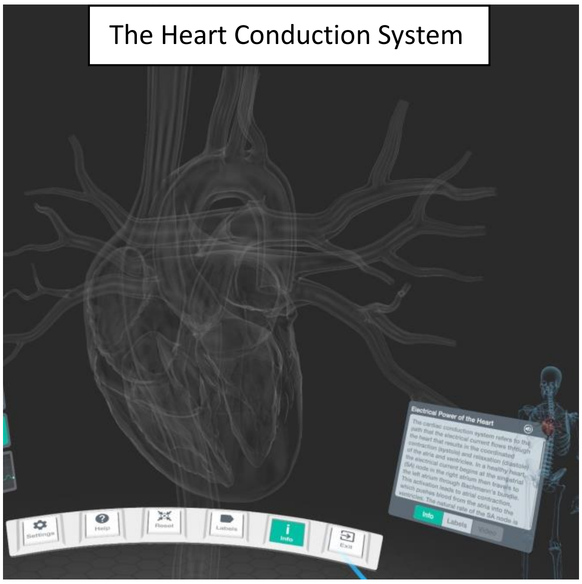
The Heart Valves – Pulmonic Valve



The Heart Valves – Aortic Valve

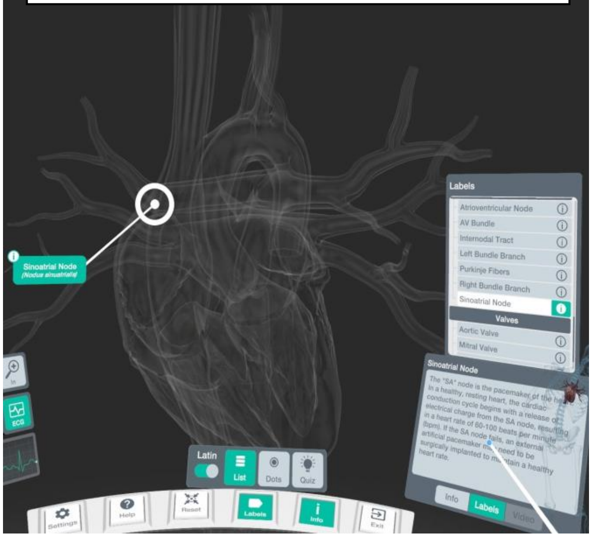


The Heart Blood Circulation

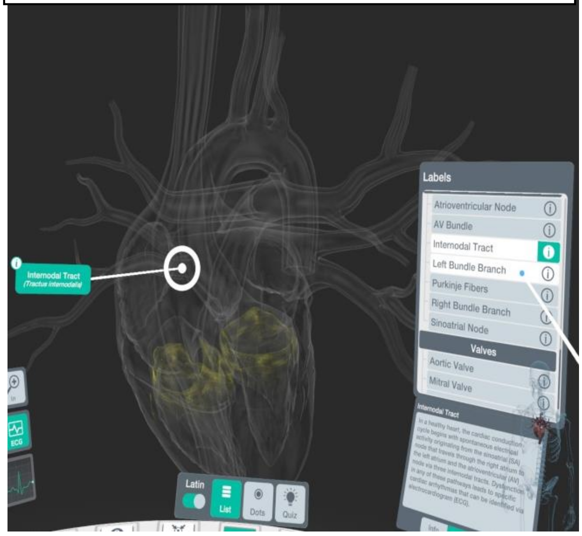


The Heart Conduction System

Heart Conduction System-Sinoatrial Node

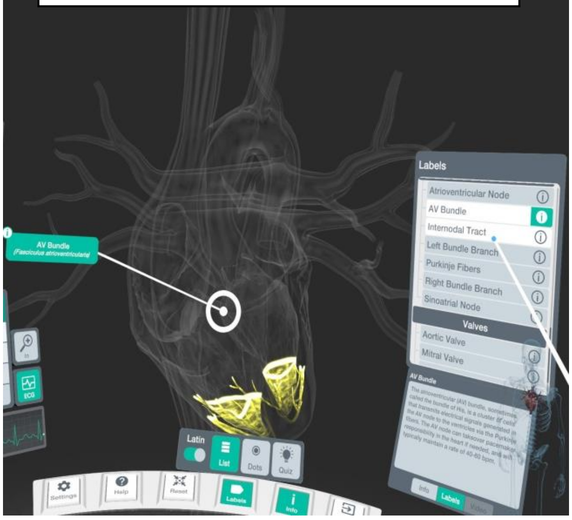


Heart Conduction System-Internodal Tract

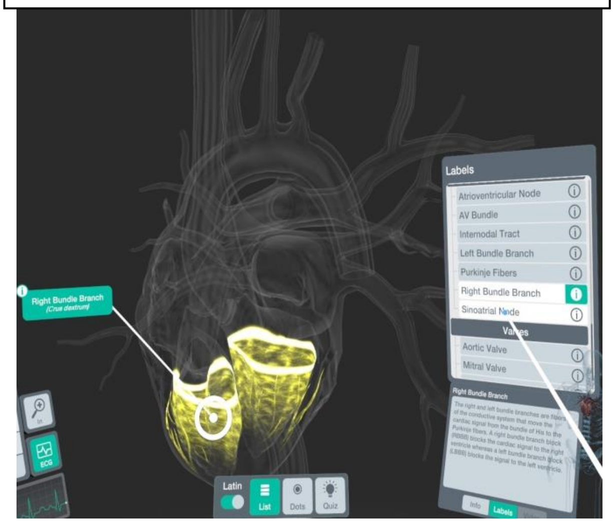


Heart Conduction System - AV Node

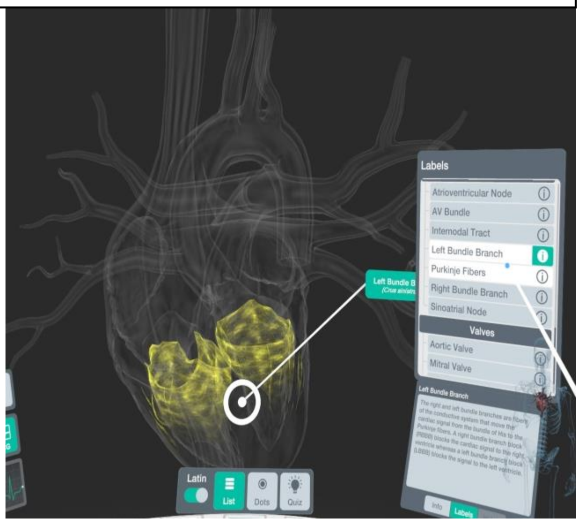
Heart Conduction System-AV Bundle

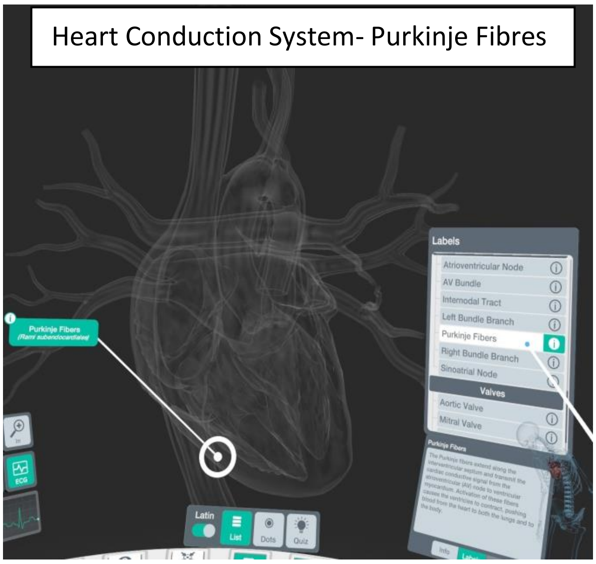


Heart Conduction System-Right Bundle Branch

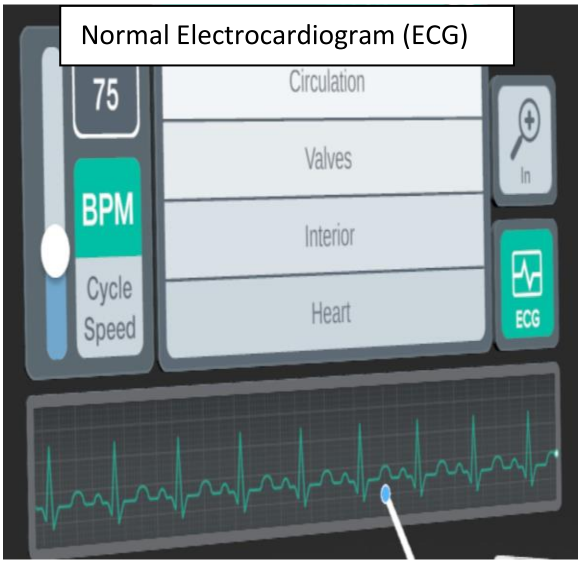


Heart Conduction System- Left Bundle Branch

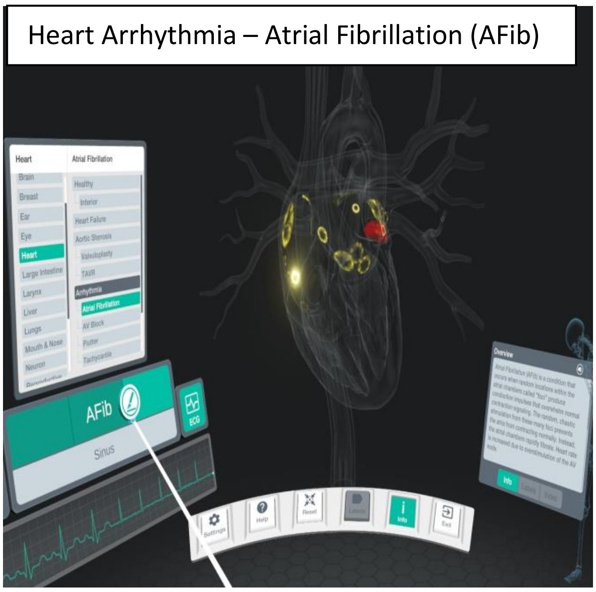




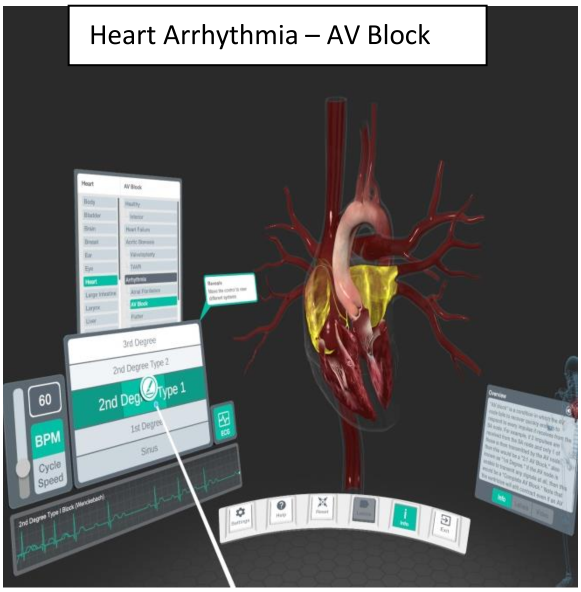
Heart Conduction System- Purkinje Fibres



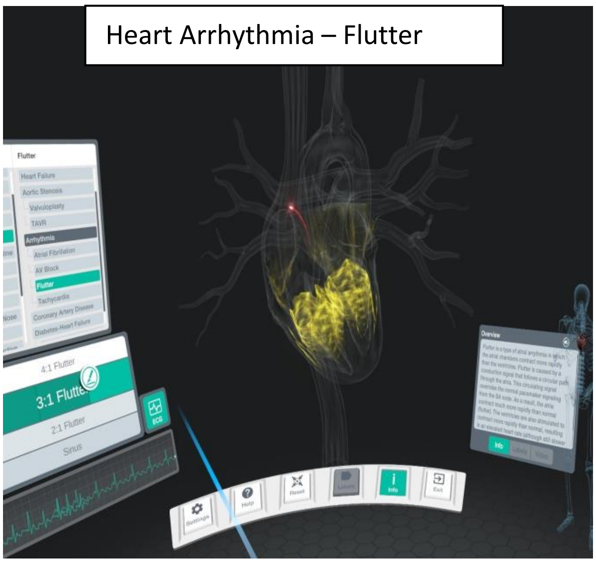
Normal Electrocardiogram (ECG)



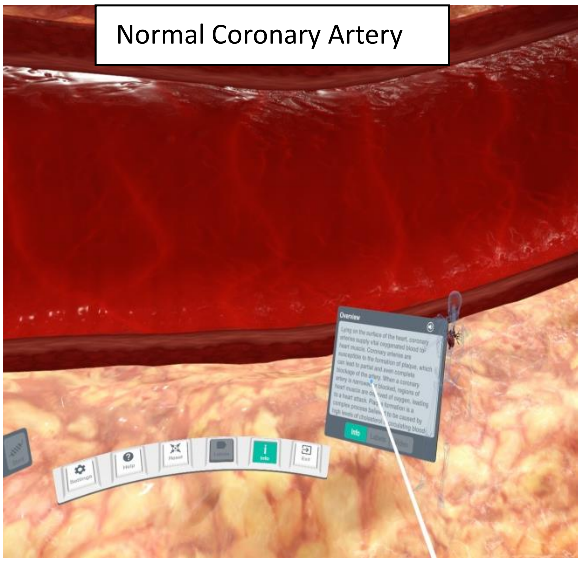
Heart Arrhythmia – Atrial Fibrillation (AFib)



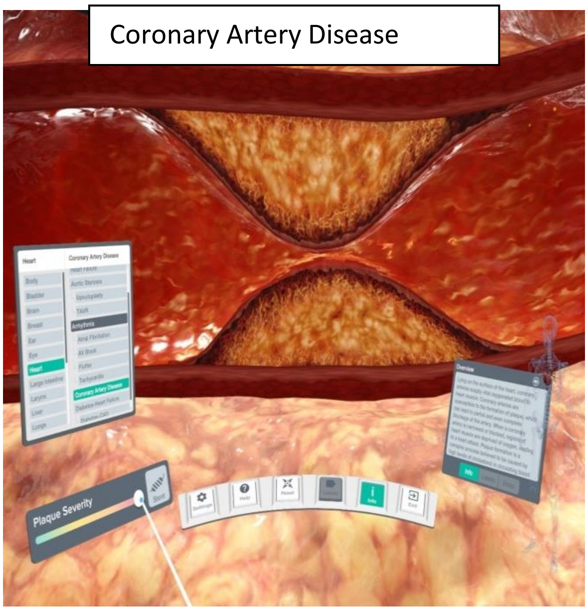
Heart Arrhythmia – AV Block

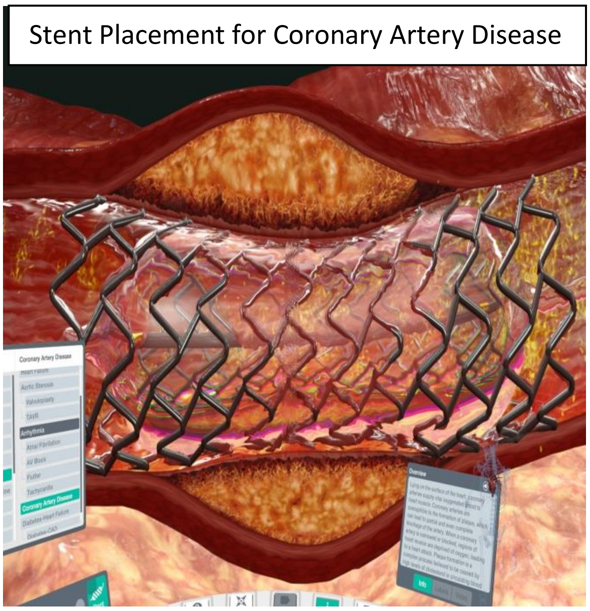


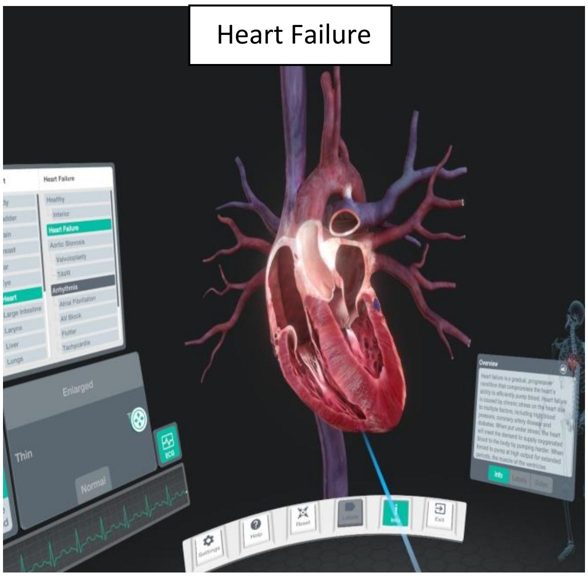
Heart Arrhythmia – Flutter

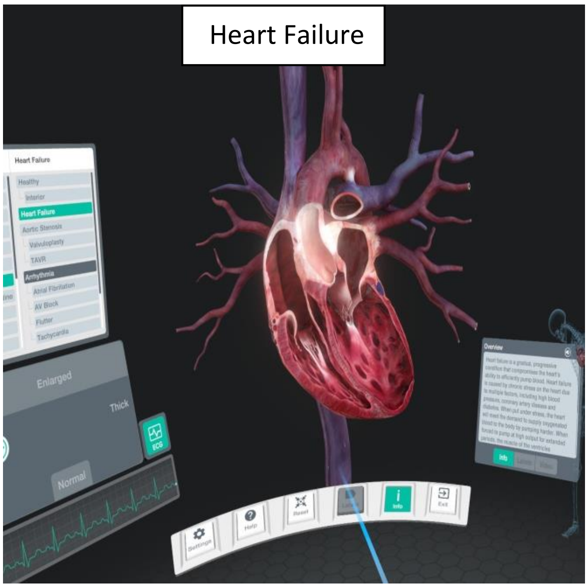


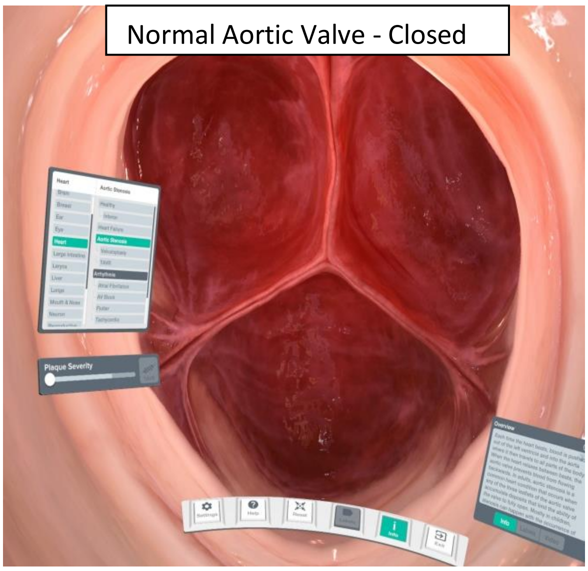
Normal Coronary Artery

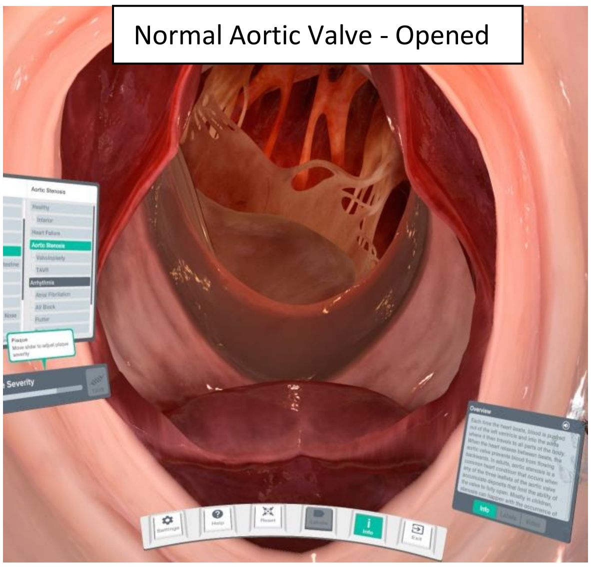

Coronary Artery Disease


Stent Placement for Coronary Artery Disease


Heart Failure

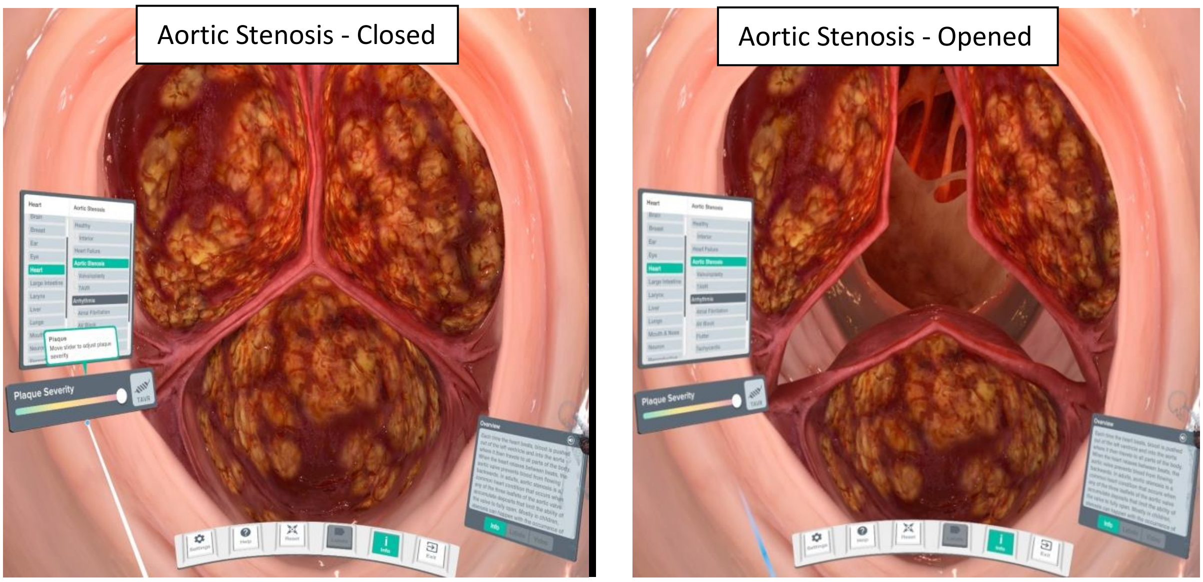

Heart Failure


Normal Aortic Valve - Closed

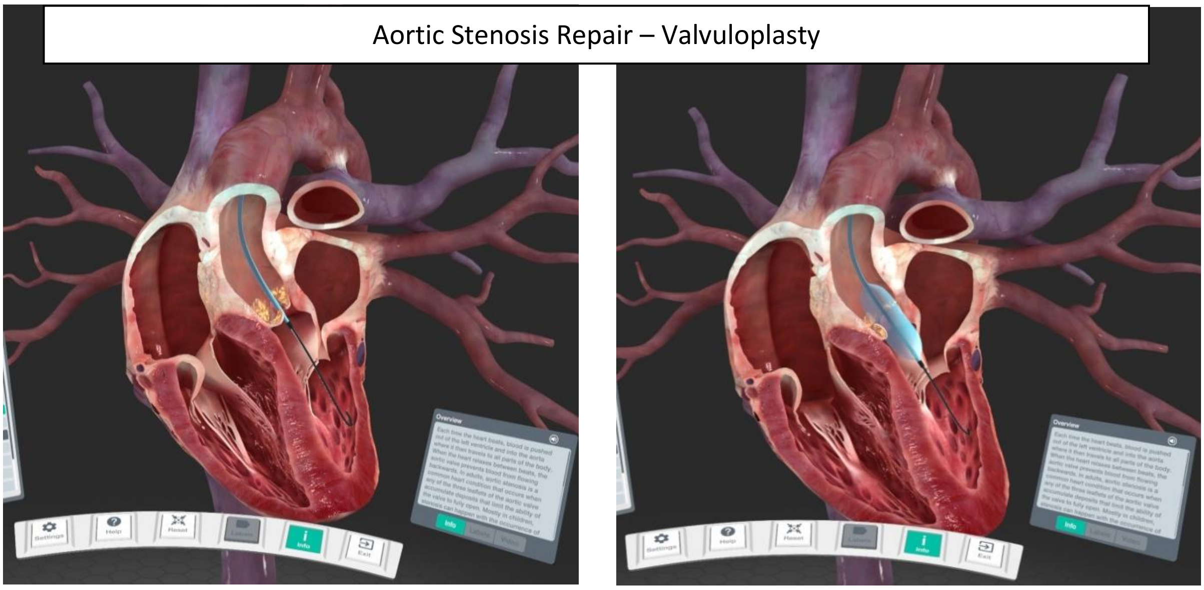

Normal Aortic Valve - Opened

Aortic Stenosis - Closed

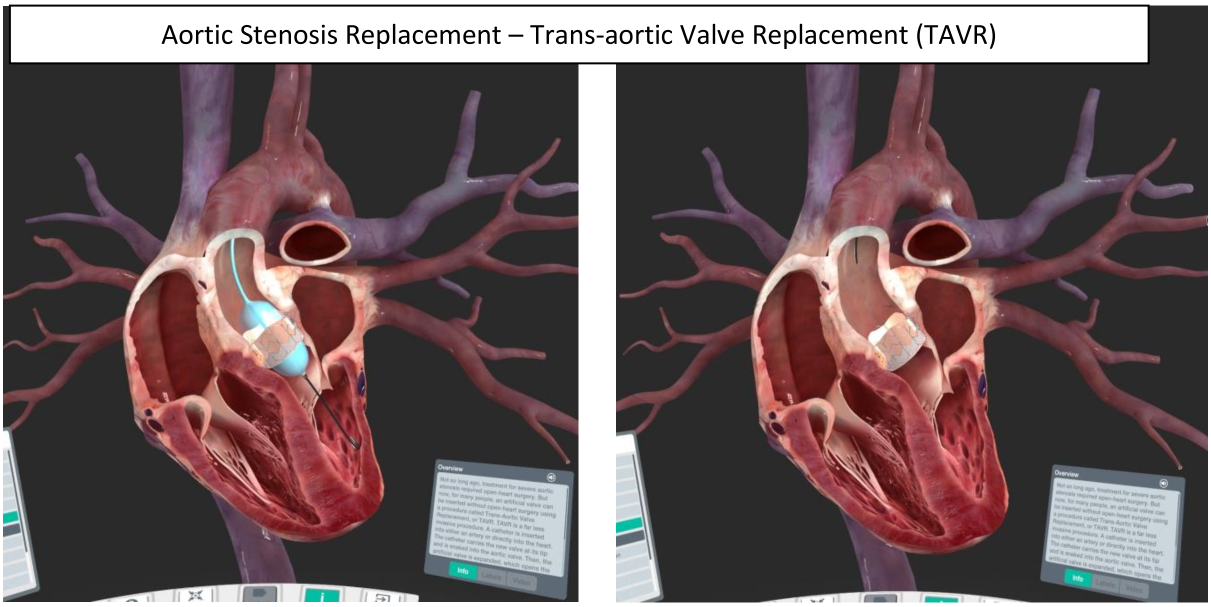
Aortic Stenosis - Opened



Aortic Stenosis Repair – Valvuloplasty



Aortic Stenosis Replacement – Trans-aortic Valve Replacement (TAVR)



Appendix 3: Control Group (Non-VR/PowerPoint Group) Learning Material

Hochschule Anhalt
Anhalt University of Applied Sciences

CARDIAC ANATOMY EDUCATION

Researcher :
Angela Odame

Supervision:
1st : Prof. Dr. Johannes Tümler
2nd : Prof. Dr. Stefan Twieg

Research Support:
Dr. med. Claudia Schadow

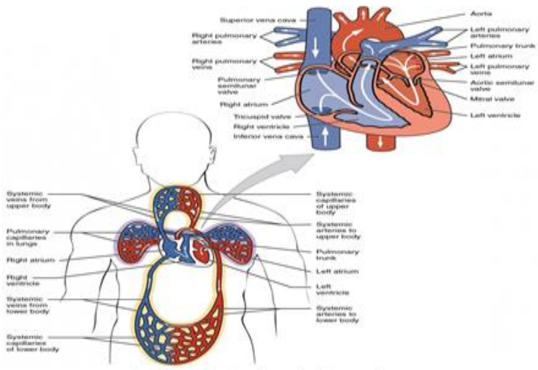
Content

- Overview of the human heart
- Heart exterior
- Heart interior : Heart chambers and valves
- Heart blood circulation
- Heart conduction system
- Electrocardiogram
- Some heart pathologies: arrhythmia ,coronary artery disease, heart failure, aortic stenosis with treatment options.

The Human Heart

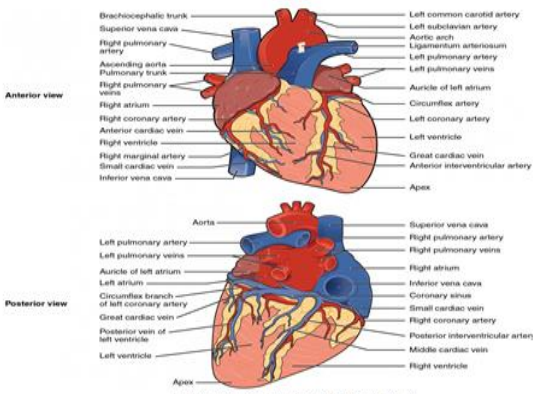
- The heart is the organ that sits at the centre of the body's circulatory system.
- It is located in the centre of the chest, behind the ribs and just slightly to the left of the sternum.
- It is the only muscle in the body that never rests.
- The heart is responsible for pumping oxygen-rich blood out to the body and for delivering carbon dioxide in the blood to the lungs where it can be exhaled.
- As the need for oxygen in the tissues increases with activity, the heart is able to meet this demand by increasing the heart rate, which results in more blood being pumped to the peripheral vascular system.
- While most adult human hearts weigh about 1 pound, the heart of a blue whale weighs about 1500 pounds.

The Human Heart Cont.



https://courses.lumenlearning.com/nemcc-ap/chapter/heart-anatomy/

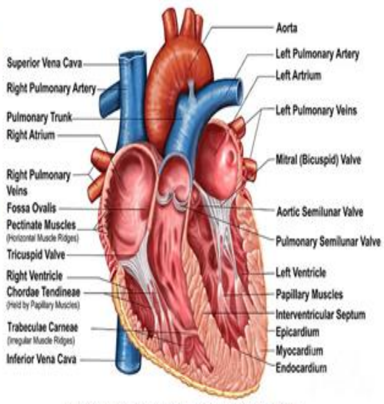
Heart Exterior (Surface Features of the Heart)



https://courses.lumenlearning.com/nemcc-ap/chapter/heart-anatomy/

Heart Interior

- The heart has 4 chambers : the right atrium, the left atrium , the right ventricle and the left ventricle and 4 valves : mitral , tricuspid, aortic and pulmonic valves.
- The right and left atria are located at the base(top) of the heart



https://nurseslabs.com/cardiovascular-system-anatomy-physiology/

Heart Chambers

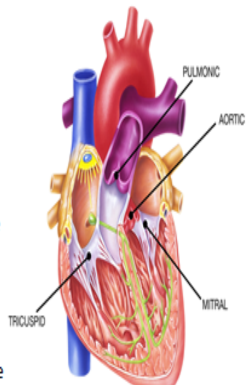
- Right atrium: Receives deoxygenated blood from the body collected into the inferior and superior vena cavae while deoxygenated blood from the heart muscle itself is brought to the right atrium by the coronary sinus.
- Right ventricle : Receives deoxygenated blood from the right atrium through the tricuspid valve. During systole(contraction), it pushes blood through the pulmonary arteries where it becomes oxygenated in the lungs. Lung conditions like chronic obstructive disease(COPD) that is frequently caused by cigarette smoking , can increase the pressure in the lungs and force the right ventricle to have to work harder to pump blood out of the heart. Overtime, this can lead to right-sided heart failure.

Heart Chambers Cont.

- Left Atrium : Receives oxygenated blood from the lungs through the pulmonary veins . Pulmonary veins are the only veins in the body that carry oxygenated blood. Once in the left atrium, the blood then moves through the mitral valve. Conduction disorders like atrial fibrillation can cause blood to pool in the left atrium where it clots.
- Left ventricle: Is responsible for pumping oxygenated blood from the heart through the aortic valve to the aorta. The wall can be up to 8 – 9 mm more thicker than the right ventricle in a healthy adult but may become thicker in the context of cardiac disease. When arteries throughout the body become hardened (atherosclerosis) from conditions like hypertension. It increases the workload of the left ventricle.

Valves

- A series of four valves help close the connection points between these chambers, preventing blood from back flowing.
- The mitral valve, a bicuspid (two leaflet)valve, separates the left atrium from the left ventricle and the tricuspid valve, a three leaflet valve, separates the right atrium from the right ventricle.
- The pulmonary valve separates the right ventricle from the pulmonary arteries as blood travels to the lungs and the aortic valve separates the left ventricle from the aorta as blood travels to the body.

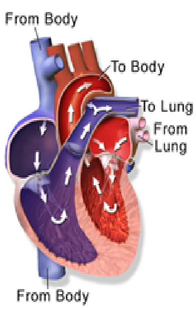


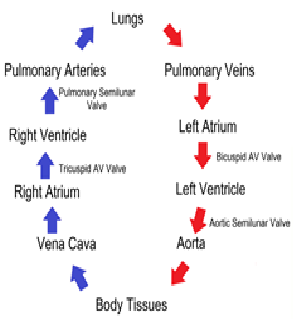
https://www.stdom.com/services/ihs-heart-vascular-institute/valvular-disease/

Heart Blood Circulation

- Oxygenated blood travels from the lungs through the pulmonary veins to the left ventricle.
- This ventricular filling process is called diastole.
- When the ventricles are full and contract(systole), the blood is pushed through the aortic valve to the aorta and the rest of the body through a complex network of arteries in the peripheral vascular system.
- Oxygen is exchanged from the blood to the tissues and the deoxygenated blood is brought back from the peripheral vessels through two large veins: the superior vena cava and the inferior vena cava.

Heart Blood Circulation Cont.





Medical gallery of Blausen Medical 2014

Heart Conduction System

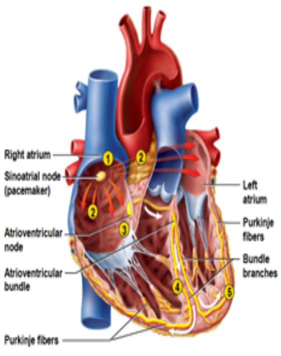
- It is the part that the electrical current flows through the heart that results in the coordinated contraction (systole) and relaxation (diastole) of the atria and the ventricles.
- In a healthy heart, the electrical current begins at the sinoatrial (SA) node in the right atrium then travels to the left atrium though Bachmann's bundle. This activation leads to atrial contraction, which pushes blood from the atria into the ventricles.
- The natural rate of the SA node is 60 – 100 beats per minute, which coincides with what is accepted as the normal range for heart rate in adults.
- The impulse then travels to the ventricles through the atrioventricular(AV) node. In the ventricles, the path is : AV node > Bundle of His > Right and Left bundle branches > Purkinje Fibres.

Heart Conduction System Cont.

- This causes the ventricles to contract, starting at the apex of the heart , and pushes blood from the ventricles out to the body and the lungs
- In an adult, a heart rate faster than 100 beats per minute is called tachycardia and a heart rate slower than 60 beats per minute is called bradycardia.
- Sinoatrial (SA) node : The natural pacemaker of the heart. If the SA node fails, an external artificial pacemaker may need to be surgically implanted to maintain a healthy heart rate.
- The atrioventricular (AV) bundle sometimes called bundle of HIS : transmits electrical signals generated in the AV node to the ventricles via the Purkinje fibres. The AV node can takeover pacemaker responsibility in the heart if needed, and will typically maintain a rate of 40 – 60 bpm.

Heart Conduction System Cont.

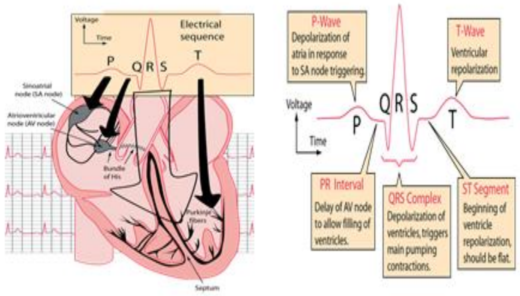
- Internodal tract : Spontaneous electrical activity from the SA node travel through the right atrium to the left atrium and the AV node via three internodal tracts.
- Right and left bundle branch : Moves the cardiac signal from the bundle of HIS to the Purkinje fibres.
- Purkinje Fibres: Extends along the interventricular septum and transmit the cardiac conductive signal from the atrioventricular(AV) node to the ventricular myocardium.



https://www.chegg.com/flashcards/chapter-19-lecture-dfefd010-8084-4adf-9737-3d50654aeedc/deck

Electrocardiogram

- An electrocardiogram(EKG or ECG) records the electrical signals in your heart. It is a common test used to detect heart problems and monitor the heart's status in many situations



http://hyperphysics.phy-astr.gsu.edu/hbase/Biology/ecg.html

Heart Pathologies

Heart disease describes a range of conditions that affect the heart. Some common heart diseases to be discussed are as follows :

- Arrhythmia : Atrial Fibrillation, AV Block, Flutter
- Coronary artery disease
- Heart Failure
- Aortic Stenosis

Arrhythmia

Heart rhythm problems (heart arrhythmias) occur when the electrical impulses that coordinate your heartbeats don't work properly, causing your heart to beat too fast, too slow or irregularly.

A few include:

- Atrial Fibrillation
- AV Block
- Flutter

Arrhythmia : Atrial Fibrillation(AFib)

- Is a condition that occurs when random locations within the atrial chambers called “foci” produce conduction impulses that overwhelm normal contraction signalling.
- The random, chaotic stimulation from these many foci prevent the atria from contracting normally. Instead, the atria chambers rapidly vibrate and the heart rate is increased due to overstimulation of the AV node.
- People with AFib are at a higher risk of stroke. Since the atria are not contracting, blood flow is disrupted. Blood is pulled into the ventricles rather than pushed by atrial contraction. This causes blood to swirl inside the atrial chambers and allows small amounts of blood to pool inside a small sack that lies next to the left atrium. Here the stagnant blood can form into blood clot. If these clots break free and get pumped out of the heart, they can travel to the brain and cause a stroke.

Arrhythmia : AV Block

- AV block is a condition in which the AV node fails to recover quickly enough to respond to every impulse it receives from the SA node.
- For example, if 2 impulses are received from the SA node and only 1 of these is then transmitted by the AV node, then this would be a 2:1 AV Block also known as 1st Degree.
- If the AV node is unable to transmit any signals at all, then this would be a Complete AV Block.
- Note that the ventricles will still contract even if an AV signal does not occur. The Bundle of HIS will take over as a pacemaker and the ventricles will continue to contract at a regular rhythm.

Arrhythmia : Flutter

- Is a type of atrial arrhythmia in which the atrial chambers contract more rapidly than the ventricles.
- Flutter is caused by a conduction signal that follows a circular path through the atria. This circulating signal overrides the normal pacemaker signalling from the SA node. As a result, the atria contract much more rapidly than normal(flutter).
- The ventricles are also stimulated to contract more rapidly than normal, resulting in elevated heart rate(although still slower than the atria).

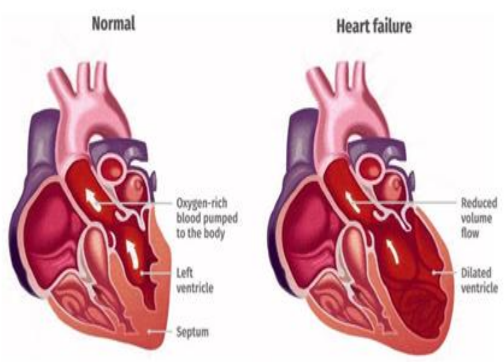
Coronary artery disease

- Lying on the surface of the heart, coronary arteries supply vital oxygenated blood to heart muscle. Coronary arteries are susceptible to the formation of plaque, which can lead to partial and even complete blockage of the artery.
- Plaque formation is a complex process believed to be caused by high levels of cholesterol in circulating blood. Cholesterol leads to the accumulation of deposits underneath the layer of cells that line the inside of the coronary arteries. This subsequently contribute to the continued growth of plaque and the gradual narrowing of regions within the coronary arteries.
- When a coronary artery is narrowed or blocked, regions of the heart muscle are deprived of oxygen, leading to a heart attack.
- A common treatment for a dangerously narrowed blocked coronary artery is placement of a stent, which opens the artery and restores blood flow.

Heart Failure

- This is a gradual, progressive condition that compromises the heart's ability to efficiently pump blood.
- This is caused by chronic stress on the heart due to multiple factors including high blood pressure, coronary artery disease and diabetes.
- When put under pressure the heart will meet the demand to supply oxygenated blood to the body by pumping harder.
- When forced to pump at high output for extended periods, the muscle of the ventricles undergoes damage, which leads to enlargement and loss of capacity.
- As heart muscle continue to fail it may lose its mass and become enlarged and thinned.

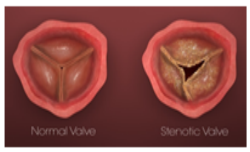
Heart Failure



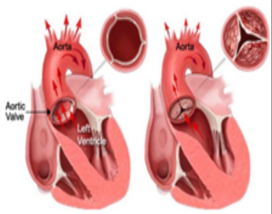
https://www.researchgate.net/figure/Illustration-of-a-healthy-heart-and-one-with-heart-failure_fig1_324018376

Aortic Stenosis

- In adults, it is a common heart condition that occurs when any of the three leaflets of the aortic valve accumulates deposit that limit the ability of the valve to fully open.
- Mostly in children, stenosis can happen with the occurrence of scarring due to rheumatic fever.
- When the aortic valve is restricted, the left ventricle must pump harder in order to deliver a sufficient amount of oxygenated blood to the body.
- Over time this extra demand can damage heart muscle, resulting in a condition known as heart failure.



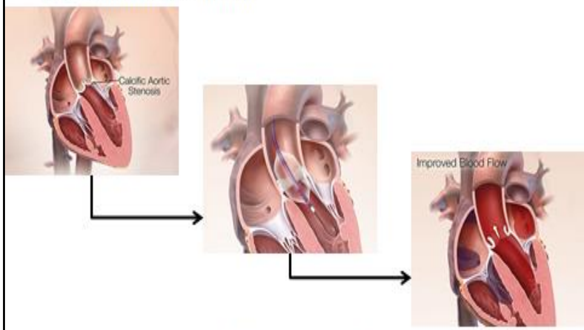
https://www.scientificanimations.com/transcatheter-heart-valves-revolutionizing-valve-replacement-surgery/



https://discover.hubpages.com/health/Aortic-Stenosis-Congenital-Aortic-Valve-Stenosis-And-Rheumatic-Aortic-Stenosis

Valvuloplasty

- A stenotic valve can be temporarily widened by a catheter procedure called balloon Valvuloplasty.



https://medmovie.com/library_id/7556/topic/cvml_0349a/summary/

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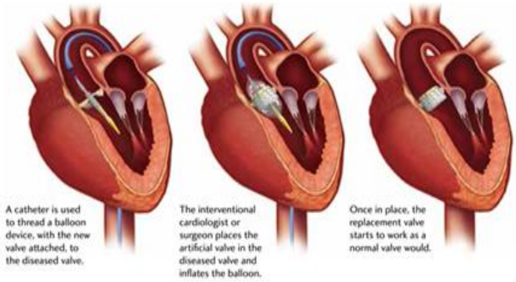
TAVR(Trans-aortic valve replacement)

- In most cases where treatment is required it is recommended that the valve is replaced using a minimally invasive procedure called TAVR(Trans-aortic valve replacement)



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Appendix 4: Subjective questionnaire in experimental (VR) group

Perceived Learning and Effectiveness of VR for Cardiac Anatomy Education
Please state your level of agreement or disagreement for the following statements regarding your experience with cardiac virtual reality.

	Left Anchor				Right Anchor
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Seeing the heart from the inside reinforced my knowledge of cardiac anatomy	○	○	○	○	○
Cardiac VR can improve visual-spatial skills	○	○	○	○	○
Cardiac VR assisted me in appreciating the size differences of different structures	○	○	○	○	○
The anatomic relationship between different structures in the heart is easily seen in Cardiac VR	○	○	○	○	○
Cardiac VR enhances anatomic integration skills	○	○	○	○	○
Cardiac VR provides useful 3D interaction and I enjoy it	○	○	○	○	○
Cardiac VR is useful for my learning	○	○	○	○	○
I learn more when I have fun	○	○	○	○	○
I enjoyed Cardiac VR	○	○	○	○	○
I like the idea of VR and would like to see more of it in my education	○	○	○	○	○

Appendix 5: Interview with Visceral Surgeon, Dr. Med. Claudia Schadow

Short work biography:

She studied human medicine from year 2005 to 2012 and further did her specialist training as a visceral surgeon from year 2012 to 07/2019. During her specialist training, she defended her doctorate in 2016.

Interviewer*: *How anatomy is effectively taught? Has studying human anatomy changed over the years? If yes, how different is it now compared to decades ago?

Response from Doctor: My own anatomy lessons looked like this: Lecture still with slide presentation and overhead projector or short schematic drawings on the blackboard, then the dissecting course. For me this was much more effective and fascinating than the lecture. We sat in small groups of 20 students around a specimen and each had certain tasks or areas to dissect. For every 2 small groups there was an anatomist who provided assistance and answered questions. This was followed by learning with "more modern" atlases. In addition, much was explained functionally in the subject of physiology.
Nowadays there are significantly fewer anatomy specimens and virtual reality or augmented reality could be integrated here: 1 corpse is primarily prepared, video-documented and then visualized. Real images can therefore be displayed in the later VR mode; real videos can be presented and viewed from all sides at the same time in VR mode. The assimilation of computed tomography images would be brilliant. Then the students can already evaluate CT images during their studies. The only weak point of this theory: there is no practical cutting and dissection.
The surgical robot is used in current surgery. At the moment, the 3 degrees of freedom of the robot arms are the only advantage compared to the older laparoscopic procedure in addition to the better optics. The robot is clearly too expensive for this gain and therefore cannot be used across the board. As I find good progress, but still in its infancy. At the same time, the operating theatres are gradually being converted into hybrid rooms: in other words, the combination of cross-sectional imaging (CT / MRT) and simultaneous operations. Examples would be: heart surgery, vascular surgery and, beginning with visceral surgery. So why is imaging not integrated into the daVinci surgical robot? I imagine: an oesophageal carcinoma is imaged by CT, then marked in the subsequent endoscopy with the already anesthetized patient using a gold clip and now the operation robot is used in the same session with the possibility of showing vessels from the computer tomograph image on the real image of the surgeon as to show augmented reality or to apply fluorescence filters to show the tumour cells. That would be a real gain. The tumour-feeding vessels can be precisely identified and defined safety distances can be worked out. This means that at the end of the day the tumour can be operated on with a good safety margin, but with maximum protection of the healthy tissue.
For such visions of the future, a good education is necessary and the first contact with newer modalities such as augmented reality and virtual reality should be given during the studies. The adaptation times to virtual reality should also be observed. Not everyone can take VR. The vestibular organ needs to be trained, in small steps. When I first encountered VR, I had a subsequent 10-minute minimal nausea. Others suffered from nausea for several hours.

Interviewer: Is the delivery or approach of the teaching content important? For example in a fun, strict, engaging manner?

Response from Doctor: Of course, enthusiasm has a great influence on our learning behaviour and also on learning success. This can already be proven in toddler age. Children whose interest has been aroused, who are enthusiastic about it, are better able to network learning content and benefit from it in the long term. But attention should also be paid to the attention time. Concentrated learning is possible over a period of 45 minutes, everything beyond that is only processed in a fleeting manner and cannot be accessed in the long term. Accordingly, a change between highly concentrated reading or frontal teaching with fun and learning in small groups is urgently indicated.

Interviewer: Do factors such as gender, subject of learning example heart, lung, liver, important to consider when teaching anatomy?

Response from Doctor: I think in medicine all students should be interested in anatomy, otherwise they have not chosen the right subject. The structure and function of the human body are at the centre of every doctor's life. Certainly the subject is too extensive to really be completely fit down to the smallest detail in all areas, but anatomy and physiology are, so to speak, the basis of all actions. The fact that the students individually decide on a subject area after completing their studies depends on their more specific interests. In addition, however, it is much more important: how are the newly qualified doctors taken by the hand in the specialist training, how are they supported. So after today's degree it is not relevant how the individual student acquired his knowledge, but he can call it up in everyday clinical practice and convey it respectfully to the patient.

We cannot teach the basic skills such as treating patients and colleagues respectfully in the course of studies anyway. So in summary again as an answer to your question: I think as a teacher I can only show students, whether male or female, individual perspectives using different learning modalities. However, this is also my job. How the individual student achieves the learning goal, he has to find out for himself and also decide. In later life as a doctor there are only guidelines and recommendations. Anything beyond that must be discussed individually with the patient and ultimately the patient decides how to proceed.

Interviewer: What are your views on using digital and modern technologies to teach and study the human body? Are they positive, negative or neutral remarks?

Response from Doctor: Today we are able to make our lessons more varied. We can cater to the individual needs of every single student. Every student can design their studies as they see fit. He can choose from the various offers himself: books, lectures, dissecting courses, microscopy, physiology as an expression of learning from the function, in the future virtual reality. The preparation effort is significantly higher than it was a few years ago, but I think that it is definitely worth it for the students.

A small negative point for me is the abundance of offers. Our subjects, which have to be covered in school and also during studies, in order to prepare the student as well as possible for his future, are now so numerous in number that the student ultimately has to make a selection. The brain performance and also the daily workload are limited. After graduating from high school, students have to learn to organize themselves and there are certainly many students in the field of medicine who like to get lost in the smallest aspects of the respective subject and are then unable to successfully complete the major subject.

Interviewer: Any recommendations for teachers and students on how best to teach and study human anatomy respectively?

Response from Doctor: Every student is an individual and learns well individually. Learning as a process is dependent on the environment, the inner attitude, the goals, and the time pressure and can be positively promoted even with smells. The offer must therefore be extensive for students. Fortunately, anatomy atlases have made significant progress over the years and can now be supported in the current age with multimedia support via app on the mobile phone, via a didactically perfectly structured program on the PC (e.g. AMBOSS) or even virtual reality. I don't think that an anatomy atlas or a surgical atlas can be completely replaced, but there are supportive options.

For me personally, acquiring knowledge in pairs was always the best option. Read texts in pairs and explain to each other. Here gaps can be found quickly and my learning effect was the best in the long term. ……………….. **End of Interview**