ANESTHESIA CRISIS SCENARIO

THE DEVELOPMENT OF AN ANESTHESIA CRISIS SCENARIO BUILDER FOR VIRTUAL REALITY TRAINING

by

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A Thesis Submitted to the
School of Graduate and Postdoctoral Studies in partial
fulfillment of the Requirements for the Degree of

MASTERS OF SCIENCE IN COMPUTER SCIENCE

ONTARIO TECH UNIVERSITY

OSHAWA, ONTARIO, CANADA

August 2019

THESIS EXAMINATION INFORMATION

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Masters of Science in **Computer Science**

Thesis title: The development of an anesthesia crisis scenario builder for virtual reality training

An oral defense of this thesis took place on August 19, 2019 in front of the following examining committee:

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Anesthesiologists are trained in the field of anesthesia and preoperative medicine; they are required to develop anesthetic plans and monitor patients vitals. Currently, anesthesia trainees are taught using traditional educational approaches (e.g., by attending lectures, reading textbooks/journals, etc.). Although knowledge is best retained by actively doing rather than passively learning, there limited active methods that are easily accessible to anesthesia trainees. Here I present a scenario builder that allows for the simple development of anesthesia-based virtual simulations that can be tailored to specific (common and uncommon) anesthesia crisis scenarios providing a potential tool for interactive skills development. A study was conducted that examined the overall usability of the scenario builder. The results indicate that the scenario builder can be used to develop anesthesia-based scenarios without merely having an extensive technology-based background.

KEYWORDS: Active Learning, Anesthesia, Framework, Interactive Learning, Simulation, Virtual Reality

STATEMENT OF CONTRIBUTION

This thesis endeavor provides the main contribution of an Anesthesia Crisis Scenario Builder (ACSB) to the field of Computer Science and specifically the area of simulations and virtual reality for the medical training for anesthesia.

- *Anesthesia Crisis Scenario Builder (ACSB)*: A computer desktop/head-mounted display (HMD)-based framework was developed using the Unity game engine. The ACSB provides a method of developing or modifying existing anesthesia-based training scenarios using the computer desktop mode modules. A module contains pre-defined tasks that can be used as building blocks to create custom scenarios and are based on the steps found in the Anaesthetic Crisis Manual (ACM) written by David Borshoff [9]. The ACSB will be discussed in greater detail in Chapter 3. Once a scenario has been developed, the trainee can go through the created scenario in a virtual operating room environment to practise (or rehearse) the actions that must be performed within a particular crisis scenario. This allows for a safe and cost-effective training environment enabling the trainee to rehearse (and learn) the appropriate steps required to handle the crisis scenario.

ACKNOWLEDGMENTS

I would like to start by thanking my supervisors, Dr. Bill Kapralos and Dr. Alvaro Uribe-Quevedo for the support and guidance throughout my research. Additionally, I would also like to thank Dr. Fahad Alam for giving me the opportunity to do an internship at Sunnybrook Health Sciences Centre and work within the anesthesia field.

I would like to thank Eric Chu and Priya Kartick, for being great friends throughout my undergraduate and graduate degree. For always having Taylor Swift work parties when we had to get work done and for Grey's Anatomy TV show nights, when we needed a break from work.

I also want to thank my parents for always believing in me and letting me puruse a degree in Game Development, which at the time they were unsure I would do anything with it as did I (but look at me now).

I also thank the National Sciences and Engineering Research Council of Canada (NSERC), the Collaborative Learning of Usability Experiences (CLUE), and the Province of Ontario for providing funding to pursue research opportunities throughout the last two years.

Last, but certainly not least, I thank my partner, Nour. Without her love and encouragement over the past 6 years, none of this would have been possible.

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ACRONYMS

VR Virtual Reality

AR Augmented Reality

QUIS Questionnaire for User Interaction Satisfaction

SUS System Usability Scale

ISTDP Intensive Short-Term Dynamic Psychotherapy

WAH Working at Heights

ACSB Anesthesia Crisis Scenario Builder

ABC Airway Breathing Circulation

VRTK Virtual Reality Toolkit

OTU Ontario Tech University

GDE Game Development and Entrepreneurship

CPR Cardio pulmonary resuscitation

HMD Head-mounted display

FOV Field of View

VS Virtual simulation

ACRM Anesthesia Crisis Recourse Management

CRM Crisis Recourse Management

FBIT Faculty of Business and Information Technology

SB Scenario Builder

VRS Virtual Reality Scenario

ACM Anaesthetic Crisis Manual

ECG Electrocardiogram

ACS Anesthesia Simulator Consultant

MRI Magnetic Resonance Imaging

CT Computerized Axial Tomography

ECT Electroconvulsive Therapy

CHISIL Collaborative Human Immersive and Interactive Lab

MRA Magnetic Resonance Angiography

SIRC Software Informatics and Research

DICOM Digital Imaging and Communications in Medicine

1

INTRODUCTION

1.1 OVERVIEW

This thesis will describe the development and application of a Virtual Reality (VR) and a virtual simulation framework for anesthesia training. The benefits that these technologies offer to medical education include: reliability, repeatability, safety, cost-effective, and the ability to recreate rare scenarios. The framework will provide medical educators with the ability to develop anesthesia crisis scenarios through a scenario builder in a comprehensive manner without the need for prior software development experience. The developed scenarios provide anesthesia trainees with an interactive and engaging platform to develop various anesthesia crisis-based skills.

In this chapter, I describe the lack of easily accessible active learning tools for uncommon anesthesia crisis scenarios. Though anesthesia has long been an innovator in the use of simulation-based training [42], the focus has traditionally been placed on manikin-based simulation despite the costs associated with purchasing and maintaining the manikins [42]. Furthermore, these manikins are housed in simulation centers whose availability is often limited and require costly resources to maintain.

1.2 MOTIVATION

VR has been defined as "the use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment" [62]. Although VR-based technologies have been available for several decades, currently their application has become popular in a wide variety of areas including entertainment, education, and medicine [75]. This is due in part to the availability of affordable computation power, the shrinking of electronic components, the rise in affordable hardware and the supposed 6.7 million early adopters [48] of VR and Augmented Reality (AR) [75]. AR is defined as computer-generated images which are displayed over a user's view of the real world. Immersive technology is the use of technology that extends or creates new realities. Immersive technologies in medical education and healthcare are increasing as more cost-effective tools are made available. Most common six medical-based applications are described as follows [31]:

i) Education and training: VR provides physicians with the tools to practice clinical procedures in a cost-effective manner that will ensure repeatability and allow trainees to practice severe and rare conditions safely. For example, The University of Montreal has developed a VR simulator called the Sim-K that allows doctors to perform complex knee replacements [31].

ii) Surgical planning: VR provides a novel method of visualizing (in three-dimensions) Magnetic Resonance Imaging (MRI) and Computerized Axial Tomography (CT) allowing surgeons the opportunity to interact with the resulting three dimensional (virtual) scans. This can, for example, will enable them to find the best possible route to tumors.

iii) Telemonitoring: VR allows surgeons to view procedures remotely and allow other surgeons and medical professionals to join surgeons virtually to assist and mentor the surgeon performing the surgery [31].

iv) Patient experience: VR helps patients obtain additional information in an interactive and engaging manner by allowing them to experience the procedures first-hand in a virtual environment [84], [74].

v) Treatment and therapies: VR has been used in recent years for creating virtual environments that are seen by patients during procedures to assist in dealing with anxiety [85]. Additionally, VR has been used to treat chronic pain [39] and is also being used on burn victims to distract them from the pain [31].

vi) Augmented reality-enhanced surgery: AR which is overlaying computer generated objects within the real world [41], is being used to overlay relevant clinic data such as MRI or CT scans. This can, for example, allow surgeons to focus on the procedure without the need to look away from the patient on the table [31].

These examples described above demonstrate that VR and AR are already being used within the medical field in part, due to affordability, accessibility, and ease of use. Additionally, we can also see an increase in virtual reality-based software within the medical field as seen in the AR VR Innovation Report of 2018, where developers are becoming more interested in developing applications for Training/Education and Medical/Healthcare compared to previous years [32]. However, despite the promise that both VR and AR hold, there are still various problems that must be addressed. More specifically, further work must examine their general effectiveness in learning, transfer of skills, and learning retention on the effectiveness of these tools is still being explored [41]. Furthermore, these tools solve specific scenarios (e.g., training for a particular medical condition such as a knee replacement) and do not allow for the scenario to be modified in a simple manner. A modular design, will allow for the "modules" to be used as building blocks to develop scenarios, and provide more learning opportunities for the field it is being developed for.

This increased interest in VR and AR has allowed for the development of different applications to assist in different parts of the medical field as previously discussed. For example, in Toronto, Canada, the University of Toronto and the Hospital for Sick Children have developed and created a 360 video for an Electroconvulsive Therapy (ECT) Simulation, where patients experience themselves on a gurney stretched out in front of them [74]. VR is also being used for patients to decrease distress during procedures [85]. For example, Wolitzky is using a virtual environment on 7-to 14- year old pediatric patients during a port access procedures to assist in reducing anxiety, pain, and distress [85]. In addition, VR is being used to assist with chronic pain by immersing users in a VR experience [39] that alleviates the patient from the pain through distraction. Additionally, the University of New England in Biddeford, Maine, USA has adopted the use of VR to teach empathy to medical students and other health professionals [19]. Another example of using VR to teach medical procedures is NeuroSimVR [51], which is a stereoscopic virtual reality spine surgery simulator [51].

Currently, there are challenges in anesthesia education and training. One of the problems has to do with students not being able to obtain the required time with an anesthesiologist to learn and observe. This is compounded with the limitation associated with manikin-based simulators and more specifically, their high cost in which they require a dedicated room with audio-video systems, separate rooms for debriefing, and training for faculty and staff around while the simulator runs [13]. Additionally, medical students are seeing reduced training hours and a lack of exposure to clinical experience [13]. There is concern whether enough time is allocated to medical students to properly learn the required skills to be a medical professional [13]. Furthermore, the residency program for anesthesia is facing various other challenges concerning education and training, and more specifically [40]:

- *Medical Educators*: Most medical educators are clinicians who teach and balance clinical practice and conduct research. Additionally, medical educators are not formally taught how to teach but are expected to do so through trial and error [40]. When a medical educator is teaching students, it is not correctly compensated or valued accordingly which leads to a lack of younger anesthesiologist wanting to teach [4]. Medical educators are accustomed to traditional methods of teaching such as textbooks and lectures which are less likely to implement new methods of teaching into their curriculum [69]

- *Time Restrictions*: There has been a reduction of time that residents have each week for on-duty learning [53], to reduce stress and fatigue and increase the quality of life [82]. Residency programs have updated their curriculum to cover the same amount of content in a shorter duration; as a result, this has caused additional stress on the faculty without an increase in resident education [60].

- *New Generation*: The current generation of residents have been raised with technology and expect it to be integrated into their teaching practices [44]. Additionally, some learners may have different preferences with how they learn, this is something that is not being taken into account [40].

To this end, I have decided to focus on creating a framework to assist in the first category i) education and training and more specifically, within the field of anesthesia. The goal of this research is to create a more readily available virtual reality-based tool that will be referred to as the ACSB. The framework will allow for the creation of different scenarios based on the end user's needs, that is, health professionals, without programming knowledge. This framework will help medical students in the anesthesia field to practice crisis scenarios and obtain exposure to an operating room and the medical instruments and tools that they will be using.

1.3 Thesis Statement

> Does the ACSB allow for the simple creation of new scenarios or modification of existing ones without a strong technical background?

This thesis will cover the design, development, and usability testing of the ACSB that I have developed with the assistance of two other student developers and a medical professional. The first student developed a system for displaying the Electrocardiogram (ECG) and manipulating it, however, it is not currently implemented fully in the ACSB. The second student assisted in developing new 3D models for the scene. The medical professional, Dr. Fahad Alam, an anesthesiologist at Sunnybrook Health Sciences Centre in Toronto, Canada, and an educator within the Department of Anesthesia at the University of Toronto in Toronto, Canada, assisted as the content expert and provided the medical knowledge related to anesthesia. The goal of this research is to develop the ACSB and determine if the ACSB is a usable, interactive, and an engaging tool that can be used to develop virtual anesthesia crisis scenarios in a simple manner and without prior software development/coding experience.

1.4 ORGANIZATION

The remainder of the thesis is organized as follows:

- Chapter 2: A brief overview of current concepts and relevant previous work in the areas of anesthesia, virtual simulation, virtual reality, crisis simulation, and related works outside of the anesthesia field that is similar to the project being developed is provided. The chapter will discuss anesthesia and its current education curriculum and where it is currently lacking. The chapter will also discuss how simulation and virtual reality will assist in the medical field and enhance training.

- Chapter 3: In this chapter, the Anesthesia Crisis Scenario Builder (ACSB) is described in detail. More specifically, details regarding the development of the ACSB was made, what was used to develop it, and the interactions allowed within the developed scenarios. Additionally, the modules will be broken down into their sub-tasks and the interactions they contain. Finally a break down on the overall development and how previous projects assisted in shaping this current project will also be provided.

- Chapter 4: This chapter covers the usability study conducted to examine the usability of the ACSB and its desktop and virtual reality portion. The chapter begins with a discussion of the study design and experimental methods. Finally, the results of the study will be presented in two parts, the desktop portion of the ACSB and the VR portion of it.

- Chapter 5: This chapter covers how the ACSB fits into the field of virtual simulation and virtual reality and how it will benefit the anesthesia education field. Furthermore, the results will be used to create a future works list that describes the future development of the ACSB. Finally, an outline of the next study will be briefly outlined.

- Chapter 6: In this chapter the main contribution of my thesis work is summarized and explained. The thesis statement will also be reviewed and a discussion regarding how the work in this thesis satisfies the thesis statement.

2

RELATED WORK

2.1 OVERVIEW

In this chapter, I provide an overview of the concepts and relevant previous work in the areas of anesthesia, virtual simulation, virtual reality, crisis simulations, and related works pertaining to the subjects of this thesis. The chapter begins with a discussion of the role and importance of simulation in anesthesia training. Finally, I will then briefly discuss VR and how it is being used in the medical field.

2.2 ANESTHESIA

An anesthesiologist is a doctor who practices within the field of anesthesia. The job includes perioperative care, which is the care before and after surgery, and developing anesthetic plans, which determines is the amount of anesthesia needed for putting a patient under anesthetics itself [20]. Additionally, an anesthesiologist also provides pain-relieving medication during surgical procedures and monitors the patient's vitals [79]. Anesthesiologists go through multiple training and education programs: four years in an undergraduate program, an additional four years in medical school, and four years in a residency program which is sometimes followed by a fellowship or a Master's degree [80]. Below, I describe the overall learning and training outcomes from each program or degree pertaining to an anesthesiologist's education:

- *Undergraduate Degree*: The undergraduate degree can be in any discipline, however it is recommended that it is within the natural sciences field [79].
- *Medical School*: The first half of medical school is based on completing science courses that teach cell, tissue biology, gross anatomy, pharmacology and

microbiology where students must attend laboratories and lectures. During the last two years, students gain experience from working in hospitals and practicing patient care. At the end of medical school, the students choose their speciality [80].

- *Masters Degree*: The Master's degree curriculum focuses on anatomy, physiology, pharmacology, patient monitoring, and professionalism in anesthesiology. Furthermore, clinical practicum training is done throughout this program [80].

- *Residency Program*: the residency program has students training at care facilities and community sites. Students receive mentorship from other anesthesiology investigators and physician scientists [5]. Lastly, during residency, trainees are taught to provide anesthesia under the supervision of an anesthesiologist [14]

- *Fellowship Program*: fellowship programs can differ depending on what the students are of interest is. For example, Anesthesia Education and Simulation fellowship focuses on preparing trainees for an academic career. Abdominal Transplantation Anesthesia, focuses on the peri-operative and intrioperative care of patients undergoing liver, kidney, kidney-pancreas and cluster transplants [56].

It is common that during the training period, a trainee may never be exposed to rare anesthetic emergencies or even during their professional medical career [14], and thus, would be unprepared if they were to encounter such a rare scenario. Anesthesiologists are required to obtain surgical cognitive and technical skills such as the ability to perform invasive procedures like endotracheal intubation, central venous catheter insertion, and epidural catheter insertion [13]. This is gained through training with manikin simulators, and hands-on experience from practicing on real patients under supervision or animal cadavers [13], [14]. Anesthesiologists are also required to maintain appropriate knowledge of complications during operation by attending lectures or passively learning it from journals and textbooks. Additionally, anesthesiologist must obtain their board certification by passing a written and oral exam; this certification expires every eight years and must be renewed [55]. In general, anesthesiologists may learn about crisis scenarios or procedures via passive learning; however, it has been shown that knowledge is, in general, best retained by actively doing rather than passively learning [83], [14]. This is especially true for anesthesiologists as the skills they require need constant practice [14]. A training simulation such as a full-body manikin simulator or a VR simulator allows trainees and current anesthesiologists to experience and practice these rare anesthetic emergencies and refresh their skills in knowledge in an active environment rather than a passive one [14].

Medical simulation replicate clinical scenarios [1], by reproducing patient encounters and creating an environment to practice technical skills as well as non-technical skills [42]. Anesthesiologists have been the pioneers in developing and furthering the use of simulation methodology in healthcare [42]. They have the most experience with manikin-based simulation for research and training [24],[46]. This can be seen in the development of the SimOne, GasMan, Sleeper , the Anesthesia Simulator Consultant (ACS), and Body [16] which will be further explained later in this chapter. They have driven the education, training and research area for medical simulations and manikin simulators [25]. Anesthesia has been at the forefront of implementing simulation-based education and adding human factors to their education program. However, this has created a silo effect [57], due to the lack of team training between anesthesiologists and surgeons, leading to inter-professional friction with significant barriers for effective teamwork [52]. However, due to the reasons above, the overall patient care may be limited despite the teaching of non-technical skills to anesthesia personnel [42].

Currently, within the anesthesia field, there is a gap in training that pertains to decision-making skills, as Gabe et al. [27] describe:

- Lack of systematic emergency procedure.
- Lack of systematic training on non-technical skills for challenging situations.

- Inability to practice to adequately integrate technical and non-technical skills for challenging situations.

As Gabe et al. [27] points out, the reason for these gaps is due to a textbook approach to medicine, a lack of accepted theories for crisis management, an acquisition of non-technical skills done via observation of role models, and the unpredictability of crisis scenarios. This has led to a lack of teaching of these skills in standard residency or postgraduate education as textbooks are mostly static and pertain to diagnosis or pattern recognition [47].

Within anesthesia, there are three primary learning outcomes with respect to medical simulation [43]: i) cognitive outcome, ii) skill-based outcome, and iii) effective outcome. Depending on how a trainee performs during a simulation training, their results fall within these three outcomes. These outcomes help determine the trainee's level of expertise and where they need to improve. It is the responsibility of the residency program to identify the gaps of the trainee and the steps required to improving upon the identified gaps. These three outcomes can help shape the overall goal of a simulation and how it is developed. More details regarding these three outcomes are provided below [42]:

- *Cognitive Outcome*: pertains to the knowledge and clinical science involved in performing procedures and the physiology (the normal functions of living organisms and their parts within the human body) and pharmacology (uses, effects, and modes of action of drugs) [42].

- *Skill-based Outcome*: pertains to the ability of single skills, this includes airway management, spinal/epidural anesthesia, catheter insertion and the proper procedure of Cardio pulmonary resuscitation (CPR) and difficult airway algorithm [42].

- *Effective Outcome*: the ability to apply proper procedure into effective patient care, and demonstrate appropriate communication, situational awareness, task distribution and leadership [42].

The three outcomes are important as they help identify the knowledge gap and limitations for trainees. It is the responsibility of the residency program to be aware of this and assist in overcoming them [42].

2.2.1 *Anesthesia Simulation Training*

In 1969, the SimOne was developed by Dr. Stephen Abbrahamson and Dr Judson Denson; it was built in collaboration with Sierra Engineering and Aerojet General Corporation. The initial idea was to recreate the anesthesia machine (a medical device that mixes fresh gas flow of medical gases and inhalational anaesthetic agents to induce and maintain anaesthesia) but soon became a full life-like manikin. The SimOne was claimed to have the advantage in training residents in anesthesia for the skill of endotracheal intubation while posing less threat to patient safety [18], [2]. After the development of SimOne, more realistic manikin simulators began appearing. For example, the GasMan, which allowed anesthesia residents to practice uptake and distribution of anaesthetic agents [58], [73] became available. Additionally, sleeper which was a screen-based simulator, had a multi-compartment model of the human physiology and pharmacology for learner purposes. Body evolved the Sleeper and included additional critical event management [22], [77] Furthermore, The Anesthesia Simulator Recorder was developed to be an expert system revolved around learning the objectives, management advice, and an automated debriefer. This new program was named the ACS; it was an evolved version of the Anesthesia Simulator Recorder and featured additional screens [67], [68]. All of these simulator examples were developed independently of each other as none were aware of each other during the time of development as explained by Cooper [16].

Medical simulations allow for trainees to learn and practice, within a group or individuals within a safe environment without the risk of patient harm [42]. By allowing trainees to practice in an environment that does not pose patient harm, this will enable them to make mistakes within the simulation and reflect on any errors they may make [26]. Additionally, if the simulation allows for pauses to be made, the trainee can pause before making an action that in typical situations they would not be able to, and either ask for assistance or take additional time to figure out the solution [29],[42]. This makes it a powerful training tool for anesthesiologists [42], and has been shown to be more effective than traditional methods (e.g. lectures, textbooks, "See One, Do One, Teach One" [1]) for teaching medical skills (e.g. airway management, ventilation,), procedures (e.g. endotracheal intubation, central venous catheter insertion, and epidural catheter insertion [13]) and most importantly teamwork (ability to respectfully hear, understand and discuss an opinion, idea or value that may be different from their own) and the ability to communicate with others [65], [70].

These benefits have led to training trainees, which in turn has the potential to increase the outcomes for patient safety and decrease health care costs such as medical equipment through medical competence [1]; however, more extensive research is required. This is important as the cost associated with manikin based medical simulations is high and requires many resources [1]. The cost to run a simulation was broken down in the work done by Cate [12] where the setup cost during the year 2006 was US $876,485 which included renovating the existing facility and equipment, a fixed cost per year of $361,425, which was a cost that does not change, and finally $311 per course hour [86]. There are ways to minimize the cost of these simulations by sharing resources from other centers from within a hospital. However, the viability of simulation centres mostly depends on external sources, rather than hospital funding it [12].

2.3 VIRTUAL SIMULATION AND VIRTUAL REALITY

VR is the use of computer modeling and simulation that allows a user to interact within a computer-generated three-dimensional environment [62]. Virtual simulation (VS) is the recreation of a real-world environment by using computer-generated scenes. VR has been used to describe different technologies such as simulators, online virtual worlds, video games, surgery simulators, Cave Automatic Virtual Environments, and Head-mounted display (HMD)s. A VR system often employs an HMD which is a piece of hardware worn on the face of the user that mostly surrounds the user's visual surroundings by having two small displays that show computer-generated imagery [41] and exchanges realities sensors input for a virtual one [21]. This allows the user to gain a sense of being immersed within a virtual environment telling the brain and nervous system to react how it would react within the real world [76].

2.3.1 *Virtual Reality Hardware*

VR dates back to at least 1968 with the first HMD being developed called the sword of Damocles by Ivan Sutherland [81], which would follow with the development of other HMDs. For example, the super cockpit [23] in the 1980s, Sega VR-1 [61] in 1990s, and in 2001, the SAS Cube [38]. However currently HMDs have recently become popular due to the growth of consumer-grade VR technologies [41]. One of the consumer-grade VR headsets being the Oculus cost in its initial release USD $1,300 compared to HMDs in 2006 which costed USD $45,000 [36]. Another consumer-grade VR headset, Google Cardboard, is made from cardboard that allows users to use their smart phone which contains gyro sensors for orientation detection. This allows the for the combination to be turned into an HMD by having the phone placed within the cardboard cutout [49] only costing 10$. Additionally, new headsets have an increase in Field of View (FOV) from 25 to 60 degrees, to being above 100 degrees [64]. This has allowed for VR to become more accessible over the past few years and allowed for it to be seen in the educational field in a much larger way. Since its introduction, VR, has always been a part of education, yet with the recent computational advances in the last couple of decades and the availability of consumer-level immersive technologies, VR and game-based technologies are transforming medical education and medicine in general. VR and game based learning technologies are making their way into the medical field and will be the next major transformation of the education curriculum [8].

2.3.2 *Video Game-based Technology*

Educators have taken advantage of the engaging and motivational aspects of video games and applied them towards education to assist in providing a higher level of interactivity, which is normally not captured in traditional learning environments [8]. These are called serious games which are video games that are mainly used for training, advertising, simulation, or education rather than purely for entertainment [33]. This has allowed for a more learner-centered approach to teaching that allows the learner (player) to explore and learn at their own pace within the game world. Additionally, they create a more active critical learning approach for the user to learn within, which has also been shown to allow for a higher retention rate [14], [78]. Additional benefits of VR and serious gaming technologies include the ability to provide a reliable environment, multi-choice, usable anywhere, and consistent feedback [66]. They also provides students and trainees the ability to practice independently, and supports a diverse selection of anatomies and pathologies with information that can be easily provided in a virtual environment rather than having to setup different anatomies or pathologies for a manikins simulator.

2.3.3 *Crisis Simulation*

The Crisis Recourse Management (CRM) paradigm is the "articulation of principles of individual and crew behaviour in ordinary and crisis situations that focus on skills of dynamic decision-making interpersonal behaviour, and team management" [28]. In a crisis scenario, anesthesiologists must showcase cognitive skills to successfully manage the resources [71]. This has led to the creation of

Anesthesia Crisis Recourse Management (ACRM) which itself is derived from the crew resource management which was originally the cockpit resources management and was used in aviation training [59]. It was then adopted into health care and more specifically anesthesiology at first; this is because anesthesia just like aviation deals with patient/passenger safety [35]. Though in someway all medical fields deal with patient safety, in the operating room it is the responsibility of the anesthesiologist to make sure the patient is under anesthetic and safe during operation [20]. Another overlap between the CRM and ACRM is that anesthesiologists and pilots share the "hours of boredom and moments of terror" work style [28]. In addition, they share the process of putting together technical skills and decision making into a every changing interpersonal environment [28]. Currently, CRM has spread to other medical fields such as critical care, emergency medicine, and multidisciplinary operating theatre care. However, it is important to note that anesthesia was first in adopting CRM into their education system [28]. ACRM is being taught both in a passive learning approach such as online modules or lectures in an active learning approach through the use of manikin-based simulation scenarios [71]. ACRM is commonly taught at a weekend boot camp using both passive and active learning methods; however, it is both demanding and costly to conduct [71].

2.4 PREVIOUS WORK

This section will cover other work that has been done within the immersive technologies field to illustrate better the current growth of VR and how more developers and medical professionals used these technologies within their areas. The Collaborative Human Immersive and Interactive Lab (CHISIL) which is part of the University of Toronto, Sunnybrook Health Science Centre, and the Hospital for Sick Children have developed a 360 video seen in Figure 1 for an ECT simulation, where patients see themselves on a gurney stretched out in front of them [74]. The purpose of this 360 video is to help patients reduce their anxiety and fear of

Figure 1: 360 Video of an ECT Simulation [74]

pain, caused by being in an unknown environment. Through this 360 video, the patient is taken through being prepared for surgery and transferred to the operating room all while being able to view their surroundings within the 360 view. Additionally, they will be informed about what is being monitored, the treatment plan, and the equipment for the procedure [74]. Currently, CHISIL is researching the effects of this 360 video on 500 patients to see if it assists with anxiety [74].

Kate Wolitzky from the Department of Psychology, University of Texas at Austin, is researching the effectiveness of VR and how it can be used to decrease stress during a port access procedure for children 7- to 14-years old. She assessed their stress through subjective self-ratings and objective physiological and behaviour ratings. The VR experience was a virtual gorilla habitat from the Atlanta Zoo seen in Figure 2 [3], which allowed the children to move around the habitat via a joystick. The study found that children who went through the VR habitat did have an overall reduced levels of distress during the procedure [85].

Ted Jones from the Pain Consultants of East Tennessee is using VR to treat chronic pain in patients. This was accomplished by using a VR application called Cool! developed by DeepStream VR seen in Figure 3, which is a fully immersive 360 degree VR fantasy landscape. An experiment was conducted with patients that were given an Oculus Rift DK2 to wear, however if the patient had head

Figure 2: virtual gorilla habitat from the Zoo Atlanta [3]

injuries, allodynia or claustrophobia, they were given a stereoscopic display [39]. The participants rated the experience highly with ten out of the 30 participants saying they felt no pain during the experience [39].

The University of New England which has adopted using VR to teach empathy with older adults, by simulating the experience of being a patient with an age-related disease. This VR simulation is to help familiarize students with resources related to older adults [19]. This was done by placing students in an immersive VR experience and allowing them to go through age-related conditions such as macular degeneration and hearing loss from the perspective of a patient [19]. The VR software was developed by Embodied Labs [45], who focus on creating experiences for users to step into a patient's life. The VR software was placed at the university's library for students to use and rate; currently, over 600 students have used the software and rated it positively. The importance of this work is to help students understand what a patient goes through to better create empathy as it is shown to increase patient care and have better outcome [6].

Figure 3: Cool! developed by DeepStream VR [39]

Embodied Labs is a development group that focuses on providing healthcare professionals and students the opportunity to experience what their patients experience to help create more empathy [45]. Embodied Labs goals are: i) improve outcomes with people-centered care, ii) build stronger teams through shared experiences, and iii) develop empathy with first-person perspectives. Embodied Labs currently has four simulations that they call labs [45]:

i) The Dima Lab: This lab allows users to experience different symptoms of Lewly Body Dementia & Parkinson's Disease and the transition from home care to care in a residential community. The goal of this research is to help the patient's caregiver to recognize symptoms, identify ways of helping with anxiety, agitation, or hallucinations and emotional burnout [45].

ii) The Clay Lab: This lab revolves around the end of life conversation. Users are put into the shoes of a veteran with stage iv, incurable lung cancer. The goal of this lab is to experience "bad news", have the conversation with the family about moving to hospice care, and experience what happens at the end of your life [45].

iii) The Beatriz Lab: This lab provides the perspective of a patient with Alzheimer's disease, and how it doesn't just affect memory. The goal of this lab is to help identify how Alzheimer's affects communication, visual and auditory processing, and how patients with Alzheimer's can be calmed and engaged. Additionally, it shows how some patients with Alzheimer's can enjoy life despite the disease.

iv) The Alfred Lab: This lab focuses on macular degeneration and hearing loss like previously discussed in the work by Dyer's Team [19]. The goal of this lab is to allow insight into the perspective and feelings of the adult and how the learner can better communicate despite the hearing and vision loss.

The NeruoSimVR [51] is a stereoscope (video captured using a twin lens system) VR spine surgery simulator that provides surgeons with the opportunity to practice and learn a spinal pedicle screw insertion procedure. The NeruoSimVR also employed a haptic device (Novint Falcon) but later switched to the Touch 3D stylus as it supports six degrees of freedom. Additionally, the Touch 3D stylus is better suited for this scenario as it allows the attaching of physical surgical tools to the end of the handle. A study was conducted and was received well by the participants as they liked the instructional design elements of the sim, and noted that surgical trainees could practice the spinal procedure and medical educators can use the simulator to show concepts related to the procedure [51].

ImmersiveTouch is a global company that develops VR training and surgical simulations and is geared towards the healthcare industry. ImmersiveTouch has a line up of VR software that is used to assist surgeons with surgical planning by using Digital Imaging and Communications in Medicine (DICOM) scans to generate various 3D models depending on the scan to view the patient's head for Neurosurgery, the body for cardiothoracic surgery, and the spine for spinal surgery. Additionally, it can be used to create an online plan for Craniomaxillofacial Surgery and surgical splints and guides by using the ImmersiveTouch tools. ImmersiveTouch lets you view these models in VR and with a set of virtual tools practice measuring, controlling, cutting, overlaying and drawing on the patient's model [37]. Though these tools are widely used, there are very few case studies on the effectiveness of these tools.

Robert Shewaga developed a severe game for anesthesia-based CRM training, which provides trainees with a simulated medical emergency within a virtual operating room. The serious game provides an interactive and engaging training experience as trainees through a laparoscopic surgery were a complication arises. The trainee must go through the correct steps to resolves these complications by using the anesthesia machine, giving instructions to the surgeon, and giving the proper medication to the patient [71]. The serious game was created by taking the non-technical skills and technical skills involved in a cardiac arrest using the advanced cardiovascular life support guidelines [71], and letting the trainee become familiar with them through this serious game. A usability study was conducted with forty participants who rated the serious game highly and found though usable, immersive and learner-centric, improvements could be made.

During the end of my undergraduate degree mI worked in a team who developed a cardiac catheterization laboratory with the goal of enhancing the patient experience by taking them through the angiogram procedure at a high level. This had them using a VR headset to take the place of a doctor performing the angiogram on a virtual patient in order to learn about the procedure [84].

PatientZero Games is a software company that has developed multiple VR simulations ranging from an anaesthesia training simulation that has the user responding to usual complications of anaesthesia. EMERGE, which is a 3D simulation for the preparation of prospective physicians for use in the emergency room. VR-TOMY, which is VR radiology lab that allows users to interact and explore the different levels of the human body. These applications were developed for multiple university hospitals such as University Hospital Frankfurt and University Medical Center Gottingen [30]

Oliver Grottke developed a simulator that provides training for regional anaesthesia and peripheral nerve blocks under different anatomical varieties. This was

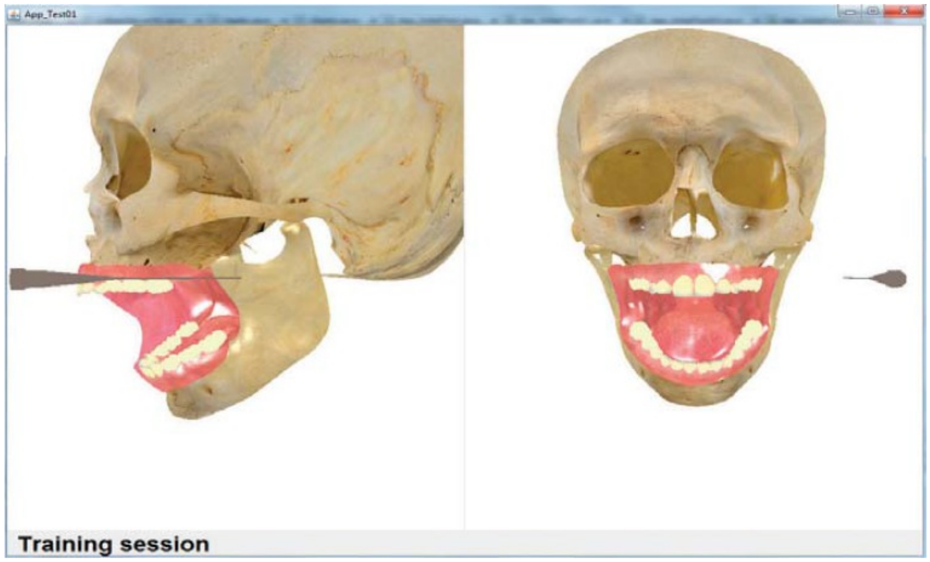

Figure 4: Dental anesthesia-training simulator for the inferior alveolar nerve block [17]

accomplished by taking MRI and Magnetic Resonance Angiography (MRA) that were visualised in combination with 3D modeling to allow for manipulation in a virtual environment. By using different patient images, it created a more flexible learning environment instead of only training users on one anatomy. Additionally, the use of rudimentary haptics was used to increase interaction [34].

A dental anesthesia-training simulator was developed for the inferior alveolar nerve block as seen in Figure 4. It provides a tactile sensation of inserting a real needle into a virtual patient using a stylus haptic device called the Phantom Omni with a carpule syringe attached to the stylus. Users must use the stylus to insert the carpule syringe into the correct spot of the virtual mucous membrane and in the correct depth, which was next to the virtual nerve. Experimental results indicated that the simulation was satisfactory for the anaesthesia training in the needle insertion task and the perception of tissues resistances [17].

2.5 SUMMARY

Anesthesia has been a leader and innovator in the area of simulation including both physical-(manikin-)based simulation and with the current development of virtual simulations. It has been shown that simulation training has positive benefits on patient care and ACRM provides additional benefits of training nontechnical, communication, and teamwork skills. This, coupled with VR, could assist in reducing the demanding resource cost that currently exists within the anesthesia curriculum. In addition, it has the added benefit of providing a more active and learner-centered teaching method which allows learners to learn at their pace and in a more interactive, and engaging environment. Additionally, there are still issues with anesthesia training as students are getting fewer hours actively training and not receiving adequate training in ACRM to prepare them for crisis scenarios. Furthermore, the works discussed have been developed, but for one static scenario, which in turn can make it difficult to develop new scenarios or modify existing ones. This is due to the need for a strong technical background. The ACSB, will allow for the creation of multiple anesthesia crisis scenarios and modification of existing scenarios based on the previously discussed module system of the ACSB.

3 ANESTHESIA CRISIS SCENARIO BUILDER

3.1 OVERVIEW

The Anesthesia Crisis Scenario Builder (ACSB) is based on the Anaesthetic Crisis Manual (ACM) book [9] covering 22 life-threatening crises that anaesthetists manage in everyday practice. Furthermore, the ACM provides concise, clear and simple instructions that can be used by any health professional who is leading or assisting in an anesthesia crisis management situation. Lastly, the ACM is endorsed and extensively referenced by the European Society of Anaesthesiology and the Australian Society of Anaesthetists [10].

3.2 SIMULATION DESCRIPTION

The ACSB was developed for this thesis in collaboration with Dr. Fahad Alam and Dr. Clyde Matava from the Department of Anesthesia, Sunnybrook Health Sciences Centre in Toronto, Canada, and the Hospital for Sick Children (SickKids), in Toronto, Canada respectively. The motivation for the development of the ACSB was to allow ease of access to simulation training since obtaining access to the simulation centers including the one at Sunnybrook Health Sciences Centre is difficult for trainees given its limited availability (it is in high demand), and associated costs (e.g., the presence a staff member/technician and supervisor present).

The ACSB was developed using the Unity game engine with a plugin called Virtual Reality Toolkit (VRTK) [1], which handles the VR interactions and allows for switching between various HMDs without the need to modify the source code/-software. VRTK was used over SteamVR, as at the time of development, it allowed

1 https://vrtoolkit.readme.io/

the existing code to be used universally across different HMDs. This allowed for the ACSB to be usable on multiple platforms. Blender [2] an open-source 3D modeling software was used to create 3D models to be used in the ACSB. Some of the operating room assets such as the anesthesia cart (which contains drug vials), anesthesia machine (which contains the ECG monitor and controls for ventilation), and various other assets that made up the operating room were re-used from previous work completed by Robert Shewaga [72]. Some of the re-used assets were modified (many to allow new and more advanced interactions upon them), and many new assets were developed and used. For example, I developed the anesthesia drug cart which contains almost all of the tools necessary for an anesthesiologist to use during a crisis scenario, which includes the arterial line and a defibrillation cart amongst others. Though the assets were modeled after an actual operating room at Sunnybrook Health Sciences Centre in Toronto, Canada, some changes were made to some of the assets to ensure that a trainee within a virtual environment could access all of the assets in the virtual world, including the monitor and anesthesia cart as well as having access to the patient (see Figure 4). Although parts of the scene were moved, in an actual operating room scenario, the anesthesiologists are able to move the anesthesia cart and anesthesia machine to best fit what they need during the operation.

The ACSB is divided into two subsystems. The first subsystem is the Scenario Builder (SB) which allows trainees to create a custom scenario based on a pre-determined list of modules. The current list of modules in the SB is based on the Anaphylaxis crisis scenario. This was chosen by Dr. Fahad Alam as it is the most common crisis scenario anesthesiologists face [63]. The Anaphylaxis scenario was broken down into pre-defined modules which can be seen in Table 1, and each contains a task associated with the steps for the Anaphylaxis scenario. Each module has a set of sub-tasks that follow the ACM and try its best to replicate what has been listed within the Anaphylaxis scenario. The complete breakdown for these modules can be found in Appendix A. These tasks are to be completed

2 https://www.blender.org/

Figure 5: 3rd person view of the operation room

Figure 6: Task list in the virtual environment

in the VRS (the second component of the ACSB which is described below), and are shown via a task list as seen in Figure B.3

To use the SB you must first open a scenario, you can then select to either create a new or load an existing one as seen in Figure 7. All scenarios are given a name and description upon being created as seen in Figure 8. Secondly, modules are added to the scenarios by selecting the "Add module" button which will present a drop-down menu which will show all of the existing modules. Third, the user selects a module and a description of the module will display as shown in Figure 9. Lastly, the module is added to the task list. Certain modules have

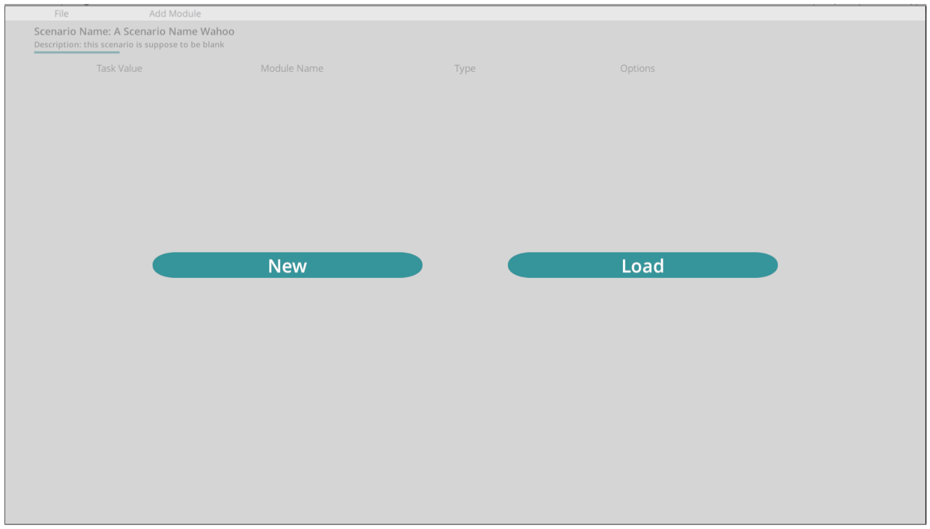

Figure 7: The New Load screen for the Scenario Builder

limitations on the amount of similar ones that are allowed in a scenario, following real-world where various actions can only happen once during a crisis scenario. The SB allows users to save and load the scenarios they have created and share them with others. This was added as it was a feature requested by the content expert Dr. Fahad Alam. Furthermore, certain modules contain additional options that can be selected depending on the one chosen to allow for certain modules to be generalizable for other scenarios. These options include: whether CPR should be commenced, which drug needs to be injected, and how many joules are needed for defibrillation. However, these options only apply to specific modules where the options are applicable.

The second subsystem is the VRS, which is where the custom scenario created can be used (e.g., by a trainee). This subsystem consists of different types of interactions required to complete modules and the available interactions are: Snap, Interact, Button, and dialogue. These interactions have been classified by myself and the syntax used in VRTK. The medical instruments within the virtual scenario are interactable meaning that they can be held by the virtual reality controllers and moved freely within the virtual space in any direction. The allowable interactions are as follows:

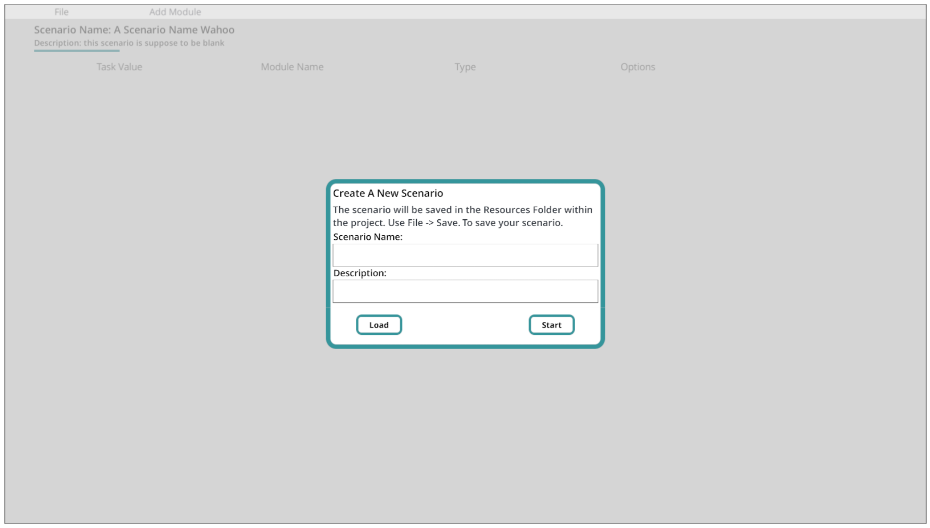

Figure 8: Input box for scenario name and description

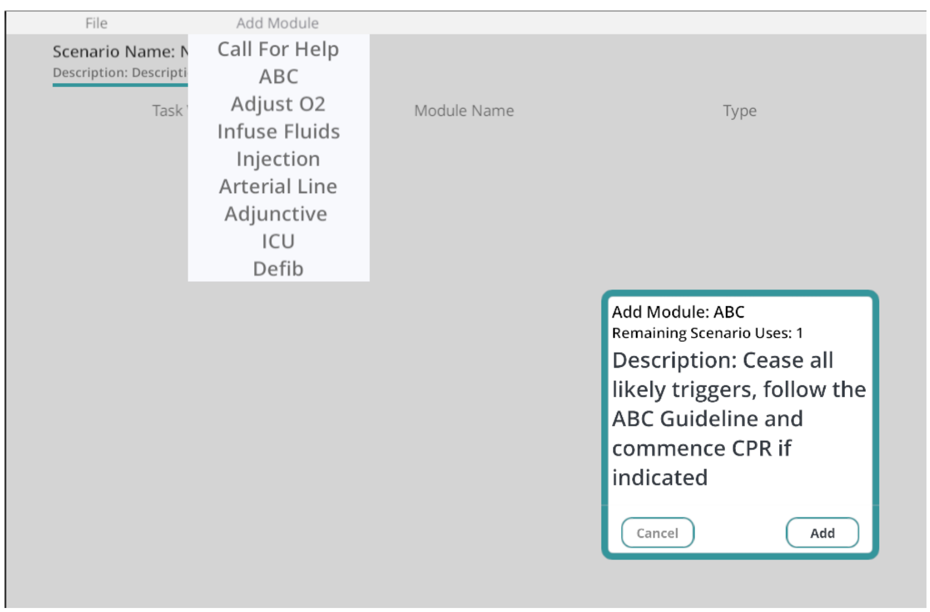

Figure 9: Menu for adding a module to the scenario and the description for a module

Table 1: Modules currently available in the framework.

Modules	Sub-tasks	Description
Call For Help	2	Call for help, communicate the problem and delegate
ABC	7	Cease all likely triggers, follow the ABC Guideline and commence CPR if indicated
Adjust O2	1	Monitor the time, SoO2 and haemodynamics
Infuse Fluids	2	Infuse fluids (at least 20ml/kg)
Injection	1	Give intravenous <Drug Name>_ mcg/kg in bolus doses. If cardiovascular collapse use _ mg
Arterial Line	2	Insert an arterial line for monitoring and gases as soon as possible - delegate if necessary
Adjunctive Therapy	1	Give intravenous <Drug Name_ mcg/kg in bolus doses. If cardiovascular collapse use _ mg
Defib	1	SHOCK immediately defibrillator is ready.
ICU	1	Move patient to ICU

- *Snap*: The snap object interaction involves the user picking up and placing an interactable object. Once an object is picked up, it can be placed within the highlighted area that has a similar resemblance to the object being held seen in Figure 10. Once the user lets go of the object within the highlighted space, the object will automatically snap to a pre-determined position as seen in Figure 11.

- *Interact*: The interact interaction is unique per object as it can be anywhere from pulling, pushing, rotating, or maneuvering the object while it is being held. For example, the syringe requires the user to hold it in one hand and pull the plunger with the other hand. The syringe also features a snap object interaction within it to allow for a drug vial to be placed on it. The drug vial requires the user to pop the cap off the drug vial so it can be used. This is achieved by using the controllers touch-pad and pressing down with the users thumb as seen in Figure 12.

- *Button*: The button interaction refers to using the monitor found within the scene attached to the anesthesia cart located near the user and interacting with it by pressing monitor buttons via the controller within the monitors screen as seen in Figure 13. This can include activating airway pressure or adjusting the O2 percentage.

Figure 10: A yellow snappable object highlighting it can be snaped

Figure 11: A gameobject that can be snapped to the highlighted area

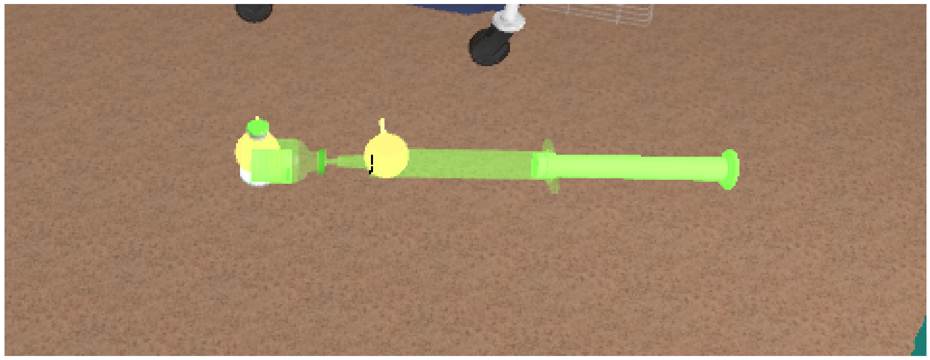

Figure 12: The highlighted drug vial is shown attached to the syringe being held

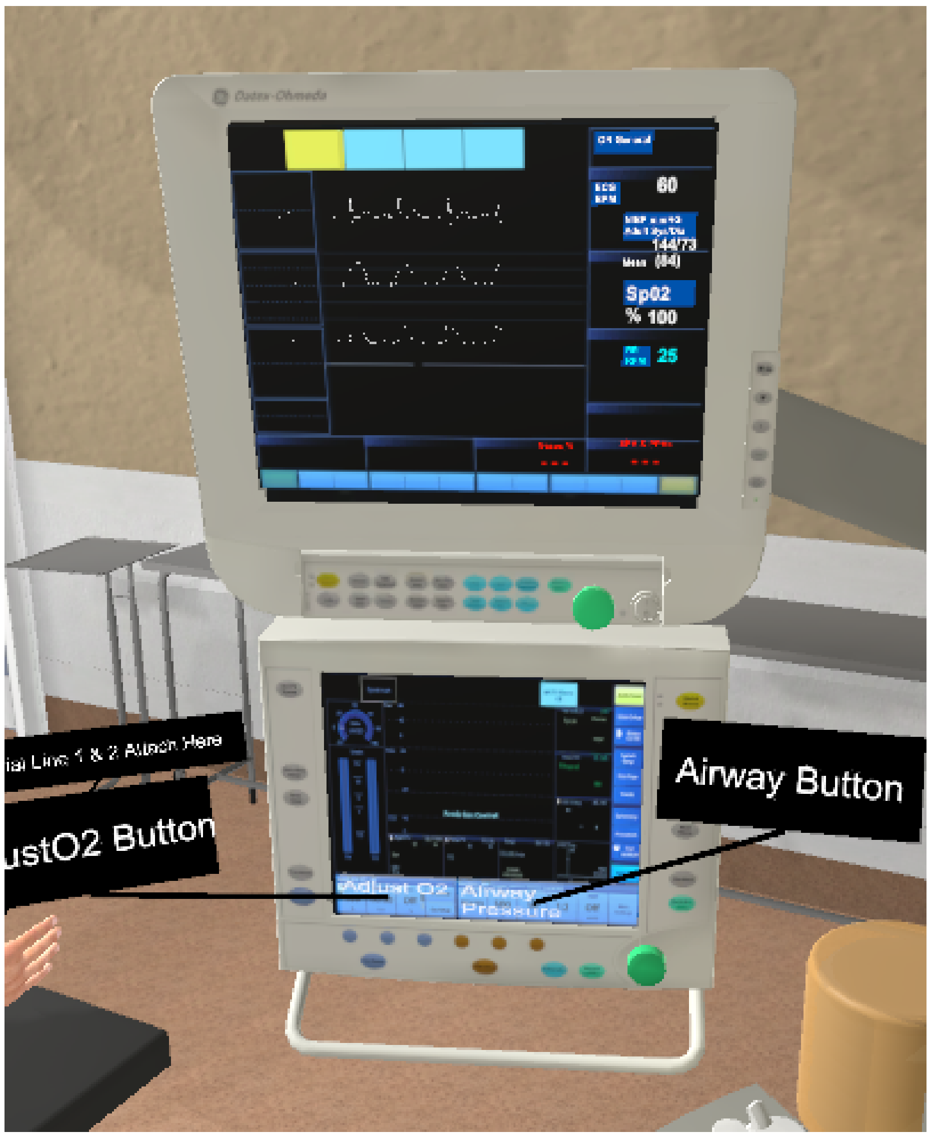

Figure 13: Monitor that allows for Adjusting O2 and Airway Pressure

- *Dialogue*: The dialogue interaction is used to communicate with virtual characters in the scene (e.g., nurse and doctor) via a dialogue wheel that can be looked at using the HMDs orientation. The dialogue wheel appears around the nurse or surgeon, which is found in the virtual environment. The dialogue interaction is done by using the HMD forward position and treating it as a laser pointer to point at the option in the dialogue wheel. There are five options that can be selected using the dialogue wheel as seen in Figure 14. Each option corresponds to a sub-task from a specific module. All tasks are presented at all times to allow the user to make the choice of which one to use and potentially select the wrong one.

3.3 ITERATIVE DEVELOPMENT

When starting the ACSB in the summer of 2018 through an internship at Sunnybrook Health Sciences Centre, I and another student began by meeting with Dr. Fahad Alam and discussing the overall goal of the project. The goal as mentioned previously was to improve anesthesia trainee learning outcomes by creating a more active learner-centered teaching method through the use of an immersive VR application. Additionally, we discussed how the currently available VR tools only support a single scenario and the need for a tool that can support multiple crisis scenarios. Furthermore, discussions about the capabilities of VR and HMDs and the interactions that were possible were also discussed. Lastly, we showcased previous work to provide him with an idea of our development experience. These previous works are:

- *Intensive Short-Term Dynamic Psychotherapy (ISTDP) Framework*: A desktop-based dialogue intervention framework which was developed using the Unity game engine for Intensive Short-Term Dynamic Psychotherapy (ISTDP) to expose psychotherapy trainees to verbal, and non-verbal communication through a virtual patient. The framework provided a method of developing

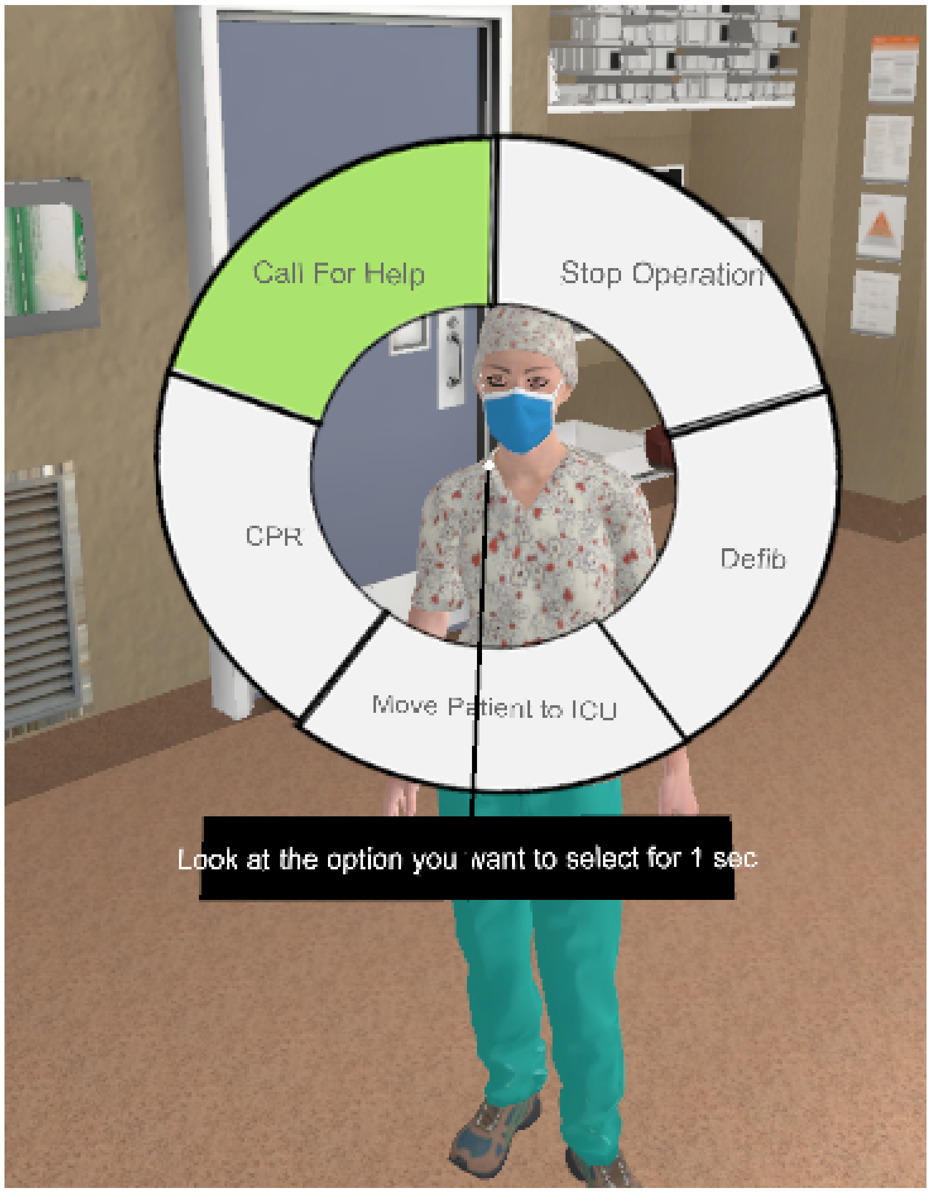

Figure 14: Dialogue wheel that appears when looking at the nurse

a dialogue scene between the user (trainee) and a virtual avatar and allowed for the facial expression of the avatar for the corresponding dialogue to be set. This provided the user a safe learning environment while being exposed to a virtual patient that may not fully express themselves verbally. This was my first attempt at developing a framework that did what is normally done in an editor (e.g., generating audio and setting blend-shapes) and have them work in run-time. These features are audio generation and creating the virtual patient's dialogue after the user has input what they want the virtual patient to say through text editing, modifying text, and loading of text files from external sources.

- *Working at Heights (WAH)*: A desktop-/VR-based framework was developed using the Unity game engine to assist in exposing users to WAH in a safe and immersive environment. The framework provided a weather control station for a user (instructor) who is viewing the scene through the desktop. The other user (trainee) who is interacting within VR is exposed to a training scenario called 100% tie-off travel restraint which will help them learn about the equipment and steps to remain safe when working at heights (WAH. This framework required objects to be connected via joints as well as snapped together within a scene. This was incorporated into the ACSB as the interaction referred to as snap. This project assisted in contributing to the ACSB as the project had to be scalable depending on how much space the user had, and more specifically, when using certain VR HMD it required the user to outline a walking space for the VR applications.

- *Cath Lab*: A serious game developed using the Unity game engine was designed to enhance the patient experience for the angiogram procedure performed in the catheterization laboratory. This project allowed a user to enter a virtual catheterization laboratory environment and perform the angiogram at a high level allowing the user to familiarize themselves with the medical instruments they will see during the procedure and briefly explain in layman terms the reason why the medical instruments are used, and the effects of the instruments on the patient. A computer-generated voice leads the user through the procedure and informs them of how the patient feels throughout the procedure. This provides the user (patient) with an additional medium to learn about the angiogram procedure that they will eventually have performed on them, immersive and interactive environment. This project was my first experience with developing in immersive VR and was my first learning experience on the capabilities of VR [84]. Finally, the central interaction system found in the ACSB originated from this project.

The design and development of the interactions were iterative and were improved upon based on feedback from Dr. Fahad Alam and other medical professionals from Sunnybrook Health Sciences Centre in Toronto, Canada. At the start of the project with Dr. Fahad Alam, meetings happened twice a week to determine how real-world interactions would fit into VR. For example, the syringe, which is handled with two hands for pulling the plunger to draw the fluid and when injecting the liquid into the patient, one hand is used. Additionally, the use of the drug vial when using the syringe had to be taken into consideration. This led to different design choices for how the syringe would interact within the ACSB. For example, the first iteration , when the drug vial was near the syringe, the user could use the touch pad on the HTC Vive controller to pull/push the syringe plunger. However, this required one hand and felt very unnatural for the medical professionals at Sunnybrook Health Sciences Centre after informal lab surveys. The second iteration used similar mechanics but added a snap interaction for the drug vial to attach itself to the syringe, while the touch pad was still used to pull/push the plunger. The current iteration allows the plunger to be grabbed with the second controller and pulled/pushed using the other controller's movement rather than using the touchpad. In addition, the drug vial has a cap that must be removed prior to attaching to the syringe, which was a requested feature by Dr. Fahad Alam as it helped demonstrate the proper steps involved in administrating drugs to a patient. It was also deemed important to have audio feedback when the drug vial was being attached/unattached from the syringe and the popping sound that associates with it.

The first iteration of the SB was based on a list system where the available modules were listed on the left side and added modules on the right of the interface. This was considered to be cluttered by Dr. Fahad Alam and changes were made to have a drop-down menu and file option at the top of the application as seen in Figure 9.

The module integration started by having each module written out on paper and broken down into two sections, sub-tasks, and realism. For the module "CallForHelp," it was broken down into two sub-tasks: i) Tell the Nurse to call for help, ii) Tell the Surgeon to stop the surgery. For realism it was noted that the nurse and surgeon should turn and acknowledge the player and respond according to the option selected. We then discussed how best to integrate this into VR. The initial ideas were voice recognition, using the touchpad on the HTC Vive controller to select options for the nurse and surgeon, and adding a menu by the nurse and surgeon that could be selected by using the HMDs orientation to look at it or interacting with it via a controller. The option that was decided upon was a menu that users look at to select an option, as voice recognition presented difficulties in detecting accents. The touchpad lessens the interaction with the nurse and surgeon and using the controller to select the options would mean having the nurse/surgeon within the play space as the user would have limited walking space. This led to the dialogue interaction which originally included four options which were placed in a two by two grid until a new module was added later. By adding a fifth option a two by two grid would no longer work. It was then changed to include a circular dialogue wheel that could allow for five options and would appear around the nurse and surgeon's head as seen in Figure 14.

To assist in informing the trainee about the medical instruments and additional information within the VRS, tool-tips were used as shown in Figure 15. The tool-tips provide additional information to the user, and can inform the user where certain objects are supposed to be placed, what an object is called, and what

Figure 15: The tool-tips that appear within the virtual environment

object the user is currently holding or hovering over with the controller. This type of tool-tip has been used in many commercial games [15]. I did not investigate whether these tool-tips cause additional cognitive load on the user. The tool-tips were added after an informal study that had a user go through the VRS, it was observed that the user struggled to locate objects and know where to place them as they lacked the medical knowledge of an anesthesiologist. Thus, the tool-tips were added to assist users who may be unfamiliar with an operating room and anesthesia cart. The original tool tip design included text above each controller to indicate what objects they were holding. Additionally, it was very difficult to read the text given its small size and limited resolution of older HMDs such as the HTC Vive.

3.4 SUMMARY

In this chapter, I have discussed the ACSB and how meetings with a content expert shaped its overall development. The development consisted of creating two subsystems the SB, which allows for the development of a crisis scenario and the VRS, which is where the crisis scenario is performed. The development of the SB consisted of programming the modules using the Anesthesia Crisis Book [9] as a reference. Additionally, I discussed the need for non-static tools that are wanted by Dr. Fahad Alam. I broke down the four interactions I have classified in the VR portion of the framework and how they pertain to the modules and how they changed throughout development. Finally, I broke down previous work done by myself and how information from those projects would assist in the overall development of the ACSB.

4 USABILITY STUDY

4.1 OVERVIEW

In this chapter, I will discuss the usability study that was conducted on the ACSB with the purpose of examining the initial functionality/usability of the ACSB and more specifically clarity of content, ease of use and the user interface, performance, and subjective satisfaction.

4.2 STUDY DESIGN

The usability study had participants running through the ACSB, which is divided into two sections: i) scenario builder (SB) and ii) virtual reality scenario (VRS). Once a section is complete, the participants completed a questionnaire comprised of two existing and verified questionnaires: i) the Questionnaire for User Interaction Satisfaction (QUIS)[7], and ii) the System Usability Scale (SUS) [11]. The SB component was completed on a standard desktop computer while the VRS was completed using the HTC Vive head-mounted display (HMD).

4.3 PARTICIPANTS

A total of 25 participants participated in the usability study, four of which did not have prior virtual reality experience. Participants were from Ontario Tech University (OTU) aged between 20-33, with the majority being between 23-26 (48%) and 20-22 (36%). Participants were mainly recruited from four different faculties, but the majority of them were from the Faculty of Business and Information Technology (FBIT) and specifically within the Game Development and Entrepreneurship (GDE) program. The GDE undergraduate participants made up 40% of the participant group. 24% of the participants were graduate participants from the Computer Science program within the Faculty of Science all of whom completed the GDE undergraduate program. The remaining participants included 24% from the Faculty of Health Sciences and 12% from the Faculty of Engineering and Applied Sciences. Participants who participated in the study did so voluntarily and were not compensated for their participation. The experiment was approved by the Research Ethics Board of OTU with reference number 15-143.

4.4 EXPERIMENTAL PROCEDURE

The usability study took place in a meeting room which was isolated from external sounds and had more than enough space for the VR setup at OTU's SIRC Building on the fourth floor (Figure 16). Each participant was greeted and provided with a consent form that they had to complete/sign (see Appendix B.4). Participants were shown how to start the Unity project and provided with a description of the task to complete, as seen in Appendix B.3. Participants were given time to read the task list and once ready were informed to start the Unity project. Once the Unity project was started, they took the time to input the scenario name and the description of the scenario. Then, using the "Add" module button previously describe in Chapter 3, they added the modules found in the task list in Appendix B.3. Once the scenario was built, participants completed a questionnaire, which is found in Appendix B.1 and B.2. Once they completed the questionnaire, they put on the HTC Vive HMD and were moved into the center of the room to complete the scenario that they had built.

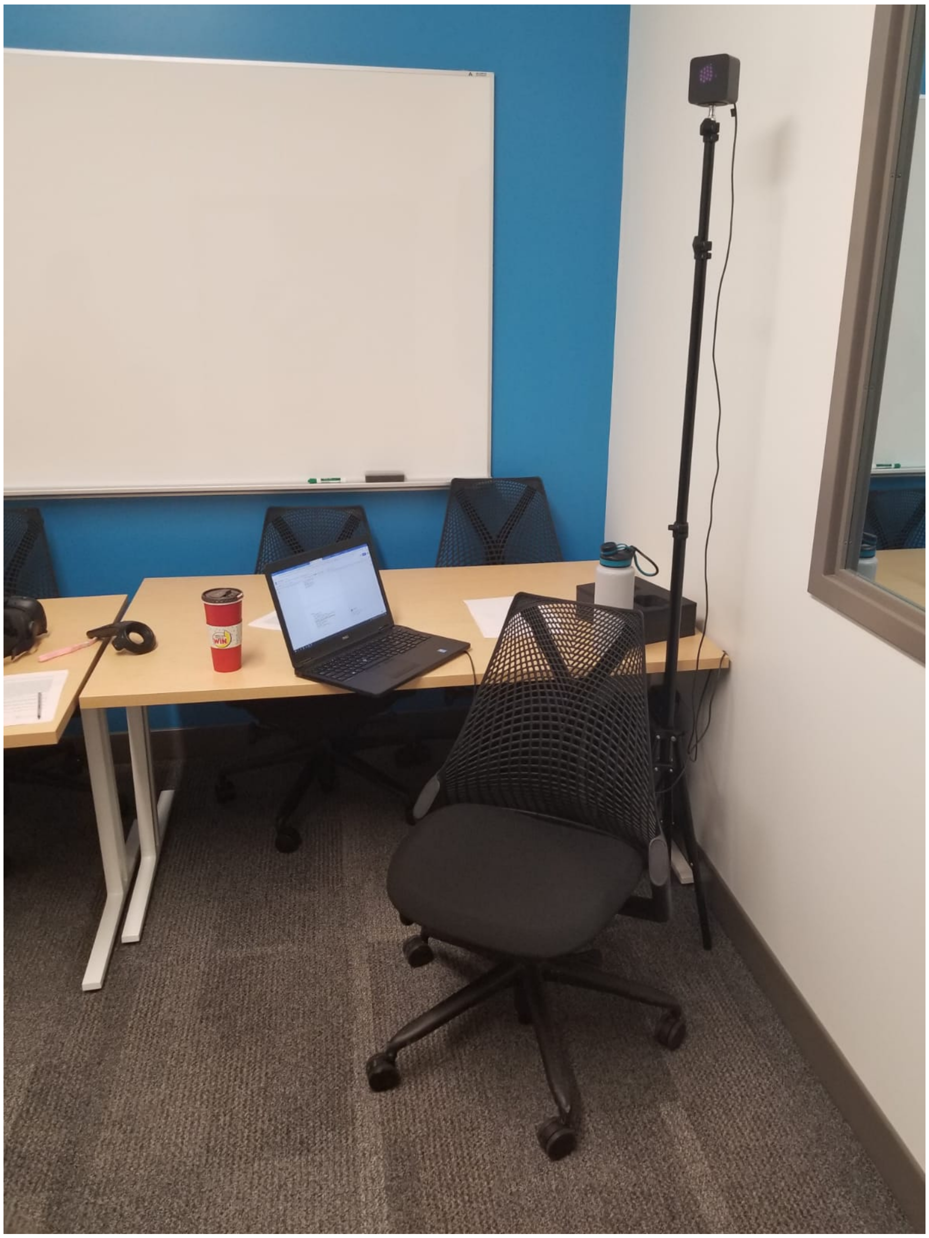

Figure 16: Meeting room in SIRC Building

4.5 METHODS

The questionnaires given to the participant consisted of the QUIS, SUS questionnaire and an open-ended section. The open-ended section allowed participants to provide additional feedback on the ACSB. The QUIS which is designed to measure the users rating based on the human-computer interface [7]. It contains five categories which are overall reactions to the system, screen, terminology and system information, learning, and system capabilities. Each section includes questions following a 10-point Likert scale (i.e., participants were required to respond with a number/ranking between 0 and 9), and are listed in Appendix B. For each of the questions, a higher ranking indicates an increase in user satisfaction to the scenario builder. A subset of sections that were relevant to the study was used from QUIS.

The SUS was designed to provide a subjective measure of the systems usability (the ease of use and learn-ability of a tool or device), and includes 10 questions which are listed in Appendix B, and are scored on a 5-point Likert scale [11]. A final score between 1-100 is obtained as follows: 1 is subtracted from the result of each odd-numbered question, and for even-numbered questions, the result is subtracted from 5. The individual scores are summed and this sum is multiplied by 2.5. A score below 68 is considered below average and a higher score shows better overall system usability [11]. Lastly, QUIS and SUS have been discussed, verified, and accepted as valid measures for usability testing for a variety of technology-based applications [7], [54], [50].

4.6 RESULTS

The following section details the results for the QUIS, SUS, game metrics and ends with a discussion regarding the open-ended questions. QUIS and SUS will be divided into two parts for the SB and the VRS. The first part will be regarding the

QUIS results for both SB and VRS, afterward the SUS and game metrics will be discussed.

4.6.1 *QUIS*

The mean results for the sections Overall Reactions to the system, Screen, Terminology and System Information, Learning, and System Capabilities are detailed in Tables 2 to 6 for the SB portion of the ACSB. Tables 7 to 11 represent the VRS portion of the ACSB. Lastly, average values will be displayed in brackets around the corresponding QUIS questions.

4.6.1.1 *Results: Scenario Builder*

This section will review the results of the SB portion of the ACSB. The initial Overall Reaction to the software was seen positively as participants found it to be easier to use rather than difficult (6.84) and felt the SB gave adequate power (7.15) when performing the tasks seen in Appendix A. However, though still positive, participants, found the program to be flexible but somewhat rigid (5.72). Furthermore, the SB was seen as stimulating but still somewhat dull (5.28) possibly due to the task they were required to complete.

	N	Minimum	Maximum	Mean	Std. Deviation
Terrible/Wonderful	24	4	8	6.50	1.063
Frustrating/Satisfying	23	2	9	6.13	1.632
Dull/Stimulating	25	2	8	5.28	1.646
Difficult/Easy	25	3	9	6.84	1.951
Inadequate/Adequate Power	20	4	9	7.15	1.694
Rigid/Flexible	25	3	9	5.72	1.860

Table 2: QUIS mean results for Overall Reaction to the Scenario Builder showing standard deviation

	N	Minimum	Maximum	Mean	Std. Deviation
Characters on the computer screen	23	3	9	7.61	1.438
Image of characters	22	3	9	7.14	1.670
Character shapes fonts	22	3	9	7.68	1.555
Highlighting on the screen	20	1	9	5.85	2.390
Use of reverse video	8	0	8	3.38	3.021
Use of blinking	5	0	8	4.40	2.881
Use of bolding	11	3	9	6.73	2.054
Screen layouts were helpful	19	3	9	6.47	1.775
Amount of information that can be displayed on screen	23	5	9	7.43	1.199
Arrangement of information on screen	23	3	9	7.09	1.703
Progression of work related tasks	18	3	9	6.50	2.093

Table 3: QUIS mean results for Screen to the Scenario Builder showing standard deviation

The SB was positively received for the Screen and Layout section as seen in Table 3. Examining Table 3, it can be seen that participants felt positively about the Characters on the Screen (7.61), the Images (7.14), Fonts (7.68), and they felt the amount of Information on the Screen (7.43) was adequate to the task given. Though no one in the participant pool was an anesthesiologist or practicing medical professional, participants still felt the Terminology used for the SB was positive as seen by a mean value of 7.86 for Computer Terminology and 7.55 for the use of Terminology Throughout the System. Participants found the interface easy to use, possibly due to the computer terminology being straight forward and similar to other software. The overall score for Learning seen in Table 5 was high as participants found discovering New Features (7.59) and Exploring these Features (7.71) was easy to do and once understood allowing for tasks to be completed in a logical sense (8.00) and a straight forward manner (8.06). The SB did not contain large number of features or steps to completing tasks hence the scores for System seen in Table 6 contains rather high scores for questions that pertain to the ACSB project itself. Overall, there are still some usability issues to work out on the SB side of the project as participants found the choice of colors for the buttons made it difficult to determine that certain buttons were clickable. In addition, the start

	N	Minimum	Maximum	Mean	Std. Deviation
Use of terminology throughout system	22	4	9	7.55	1.683
Work related terminology	20	4	9	7.65	1.599
Computer terminology	21	5	9	7.86	1.493
Terminology relates well to the work you are doing?	18	1	9	7.17	2.007
Computer terminology is used	18	2	9	7.56	1.917
Terminology on the screen	17	5	9	7.82	1.551
Messages which appear on screen	17	2	9	6.71	2.201
Position of instructions on the screen	19	2	9	7.21	2.394
Messages which appear on screen *	16	2	9	6.75	2.206
Instructions for commands or functions	17	3	9	6.41	2.093
Instructions for correcting errors	11	2	9	5.36	2.248
Computer keeps you informed about what it is doing	17	1	9	6.24	2.562
Performing an operation leads to a predictable result	17	2	9	7.41	2.063
Controlling amount of feedback	13	1	9	6.77	2.351
Length of delay between operation	17	3	9	7.88	1.833

Table 4: QUIS mean results for Terminology and System Information to the Scenario Builder showing standard deviation

screen that asks the participant to create a new scenario or load an existing one, wasn't clear on where they had to click to select one of those two options.

4.6.1.2 *Results: Virtual Reality Scenario*

This section will focus on the second questionnaire given to participants after they had completed the VRS which was based on the scenario they had built in the previous portion of the study using the SB. The Overall Reaction which is seen in Table 7, was received positively as participants found the VRS to be stimulating and wonderful, and found it somewhat easy to use. Some participants struggled to grasp the depth within VR as observed when they attempted to interact with objects and they would not reach out far enough for it to interact. The overall values for the Screen seen in Table 8 was rated highly across all questions with all being above 6.70. The two lowest scores were Image of Characters, and Screen

	N	Minimum	Maximum	Mean	Std. Deviation
Learning to operate the system	24	1	9	7.08	2.145
Getting started	22	2	9	6.55	2.385
Learning advanced features	10	2	9	6.90	2.132
Time to learn to use the system	20	4	9	7.50	1.732
Exploration of features by trial and error	16	5	9	7.25	1.238
Exploration of features	17	5	9	7.71	1.312
Discovering new features	17	5	9	7.59	1.326
Remembering names and use of commands	14	3	9	7.00	2.418
Remembering specific rules about entering commands	12	3	9	7.08	2.021
Tasks can be performed in a straight-forward manner	16	4	9	8.06	1.389
Number of steps per task	20	5	9	7.75	1.293
Steps to complete a task follow a logical sequence	20	5	9	8.00	1.257
Feedback on the completion of the steps	17	2	9	6.88	1.799

Table 5: QUIS mean results for Learning to the Scenario Builder showing standard deviation

Layouts were helpful, this can be due to the natural VR HMD resolution and how the text can be blurry for older HMDs. The highest score was 8.08 for Highlighting on the screen, this can be due to the tool-tip highlighting within the scene and how it assists participants in finding certain objects (Seen in 15). The tool-tips were seen positively as they were clear and visible and uncluttered by other objects within the scene, though the text had a natural blur to it due to the resolution of the HMD, as mentioned before. However, despite the ratings being high for the screen, multiple participants commented that although the tool tips were helpful, they were overwhelmed when they were first appeared in the virtual environment.

As seen in Table 9, participants found the terminology used within the VRS was useful and adequate, particularly for the task list presented on the wall to help them track progress. Though some participants found some minor grammatical errors within the task list, the general idea of what needed to be done was still clearly conveyed. The lowest score for Terminology was Instructions for correcting error (5.06) this is because no information was being provided to inform the par-

	N	Minimum	Maximum	Mean	Std. Deviation
System speed	24	5	9	8.50	1.063
Response time for most operations	22	4	9	8.45	1.371
Rate information is displayed	21	5	9	8.38	1.161
The system is reliable	24	4	9	7.88	1.484
Operations are	16	5	9	8.06	1.237
System failures occur	18	6	9	8.50	.924
System warns you about	8	0	9	4.50	3.207
System tends to be	16	1	9	6.38	2.986
Mechanical devices such as fans, disks, and printers	8	1	9	4.50	3.117
Computer generated sounds are	7	2	8	5.00	1.826
Correcting your mistakes	11	2	9	7.45	2.207
Correcting typos	6	4	9	7.50	2.074
Ability to undo operations	10	5	9	7.50	1.509
Ease of operation depends on your level of experience	14	2	9	5.57	2.102
You can accomplish tasks knowing only a few commands	16	5	9	8.00	1.211
You can use features/shortcuts	7	2	9	6.14	2.610

Table 6: QUIS mean results for System Capabilities to the Scenario Builder showing standard deviation

ticipant that they were doing something incorrectly, and, this caused the time to complete some modules to be longer than. Participants found once they learned how to perform an interaction within the scenario, they were able to complete it a second time much faster, which is seen in Table 10. The system lacked the ability to undo operations (5.8), and the system does not warn the participant (5.87) if a mistake is made. Participants enjoyed how fast the system reacted to their actions, especially the snap interaction which most participants found was smooth and responsive. The System speed score is 8.20 and Response time for most operations being 8.24, this made learning the interactions and going through the steps to be smooth in terms of transition and paced with the participant being able to take their time.

	N	Minimum	Maximum	Mean	Std. Deviation
Terrible/Wonderful	24	3	9	7.00	1.474
Frustrating/Satisfying	25	3	9	5.68	1.796
Dull/Stimulating	25	6	9	7.80	1.080
Difficult/Easy	25	2	9	5.68	1.930
Inadequate/Adequate power	24	2	9	7.13	1.963
Rigid/Flexible	25	2	9	6.04	2.071

Table 7: QUIS mean results for Overall Reaction to the VRS showing standard deviation

4.6.2 *SUS*

The SUS score for the SB portion of the ACSB was 75, Table 12 shows the average value for each part of SUS. This showed that the system was usable. However, there are still quality of life issues that exist within the SB. The VRS had a SUS score of 69.6 which is above average in terms of the SUS Scoring system. This shows that although the VRS portion is usable, improvements can be made before being tested with medical professionals and more specifically anesthesiologists. A list of improvements will be further discussed in Chapter 5.

4.6.3 *Game Metrics*

During the VRS portion of the study, the system collected metrics on how long it took the user to complete each module and the tasks associated with it; these tasks are outlined in Appendix A and listed in Table 1. However, although a module may include one or more sub-tasks, the time collected was the overall time to complete the entire module and not the individual sub-tasks. Another metric collected was the number of times the user looked at the task list, this task list is located on the wall of the operating room as seen in Figure 6 and discussed in Chapter 3. This task list showed the current module being completed and the

	N	Minimum	Maximum	Mean	Std. Deviation
Characters on the computer screen	25	2	9	7.00	2.121
Image of characters	25	2	9	6.72	1.860
Character shapes fonts	25	4	9	7.60	1.323
Highlighting on the screen	24	6	9	8.08	1.100
Use of reverse video	4	4	9	7.25	2.217
Use of blinking	8	4	9	7.13	1.458
Use of bolding	9	6	9	7.56	1.014
Screen layouts were helpful	21	5	9	6.95	1.203
Amount of informati on that can be displayed on screen	23	5	9	7.61	1.158
Arrangement of information on screen	24	3	9	7.04	1.654
Progression of work related tasks	24	3	9	7.00	1.694

Table 8: QUIS mean results for Screen to the VRS showing standard deviation

sub-task(s) associated with it. In addition, the time that participants spent looking at the task list was also collected for each module. The average time for these three metrics is provided in Figures 17 to 19.

The reason the total duration to complete each module was collected was to compare the overall duration between modules with similar interaction types. The dialogue interaction is apart of the call for help, defibrillation and ICU modules, the call for help contains two uses of the interaction, one for the nurse and one for the surgeon. The goal was to compare if the time to complete the defibrillation and ICU tasks would be less because the participant had already performed the dialogue interaction prior in the call for help module. Similarly, the snap modules such as infuse fluids and arterial both contain two snap interactions, both of which are located on opposite sides of the patient. Ideally the second time the user performs the snap interaction the time to complete within a similar module would be less.

As shown in Figure 17, the call for help took on average 71 seconds to complete, while defibrillation took 22 seconds and ICU took 12 seconds. We can see that the time to complete an interaction decreases once completed. Similarly for the snap interaction, infuse fluids on average took 63 seconds with arterial line taking 52

	N	Minimum	Maximum	Mean	Std. Deviation
Use of terminology throughout system	25	6	9	8.24	.926
Work related terminology	21	6	9	8.33	.966
Computer terminology	20	6	9	8.20	1.056
Terminology relates well to the work you are doing?	22	2	9	7.82	1.593
Computer terminology is used	19	6	9	8.26	.933
Terminology on the screen	23	5	9	7.91	1.203
Messages which appear on screen	25	4	9	7.36	1.440
Position of instructions on the screen	25	3	9	8.00	1.443
Messages which appear on screen *	25	4	9	7.48	1.358
Instructions for commands or functions	24	2	9	7.25	1.847
Instructions for correcting errors	16	0	9	5.06	2.720
Computer keeps you informed about what it is doing	18	1	9	6.28	1.934
Performing an operation leads to a predictable result	23	3	9	7.00	1.595
Controlling amount of feedback	17	2	9	6.53	1.972
Length of delay between operation	24	1	9	7.67	1.949

Table 9: QUIS mean results for Terminology and System Information to the VRS showing standard deviation

seconds. The difference between these two isn't as significant, possibly due to the fact that the objects that are snapped for these modules are found in different locations. However, for the dialogue interaction, it is completed using a dialogue wheel which was previously talked about in Chapter 3, this wheel is always with the nurse or surgeon and does not require additional time to locate it.

4.6.4 *Computer Science vs Health Science*

In this section, I will be looking at the performance by comparing the game metric data and SUS score of Computer Science participants and Health Sciences participants. I am comparing this data as those with a Computer Science background have experience in user interfaces and health sciences participants are the potential users with limited (if any) user interface design experience. This is of course

	N	Minimum	Maximum	Mean	Std. Deviation
Learning to operate the system	25	3	9	6.88	1.536
Getting started	25	2	9	6.56	1.850
Learning advanced features	20	2	9	5.75	1.888
Time to learn to use the system	24	3	9	6.63	1.837
Exploration of features by trial and error	24	3	9	6.83	1.659
Exploration of features	24	5	9	7.71	1.334
Discovering new features	25	5	9	7.12	1.166
Remembering names and use of commands	23	3	9	6.61	2.105
Remembering specific rules about entering commands	21	4	9	7.10	1.261
Tasks can be performed in a straight-forward manner	24	3	9	7.00	1.560
Number of steps per task	25	4	9	7.92	1.187
Steps to complete a task follow a logical sequence	24	4	9	7.38	1.469
Feedback on the completion of the steps	24	4	9	7.21	1.532

Table 10: QUIS mean results for Learning to the VRS showing standard deviation

only an observation and to make full conclusions a more formal study would have to be conducted. CSgaze and HSgaze refers to the amount of times they looked at at the tasklist in the VRS. On average Computer Science participants looked at the task list 6.46 compared to Health Sciences participants at 7.94 seen in Figure 20. CSgazedura and HSgazedura also refer to the overall duration each group spent looking at the task list. Figure 22 shows us that Computer Science participants looked at the task list just as long as Health Sciences participants but on average would look at the task list less. CSDuration and HSduration refer to the time it took to complete the entire VRS and is shown by Figure 21, as we can see Health Sciences participants overall took longer to complete the scenarios with a mean value of 94.9 compared to Computer Science participants with a mean value of 62.9. An individual SUS score was calculated to compare how each group found the SB and VRS. Computer Science participants gave the VRS a SUS score of 60.83, which is less than 68 which indicates a below-average rating [11]. However, they found the SB to be usable with a score of 80.3. Health Science participants despite taking longer time to complete the scenario found the VRS to be more usable with

	N	Minimum	Maximum	Mean	Std. Deviation
System speed	25	4	9	8.20	1.190
Response time for most operations	25	4	9	8.24	1.128
Rate information is displayed	24	6	9	8.21	.884
The system is reliable	25	4	9	7.08	1.320
Operations are	23	5	9	7.39	.988
System failures occur	24	2	9	7.17	1.993
System warns you about	15	0	9	5.87	2.642
System tends to be	19	2	9	6.84	2.007
Mechanical devices such as fans, disks, and printers	14	5	9	7.50	1.653
Computer generated sounds are	18	3	9	6.56	1.790
Correcting your mistakes	21	4	9	7.24	1.700
Correcting typos	4	7	8	7.50	.577
Ability to undo operations	15	3	9	5.80	2.042
Ease of operation depends on your level of experience	22	3	9	6.45	1.792
You can accomplish tasks knowing only a few commands	23	4	9	6.91	1.203
You can use features/shortcuts	14	2	9	6.21	1.805

Table 11: QUIS mean results for System Capabilties to the VRS showing standard deviation

a score of 69.16. Lastly, Health Sciences participants found the SB to be usable with a SUS score of 70.

4.7 STUDY DISCUSSION

Following the results of the usability study and the comparison of computer science and health sciences student, it is necessary to reflect on the usability study. The results of the study and the open feedback collected, indicate a multitude of improvements that will improve the overall usability and flow of interactions. For the SB, it was indicated that the color scheme for the menu bar made it difficult to identify what was and wasn't a button. Additionally, there were no hints or form of tutorial to teach the user how to add modules other than the external task list given to them. Lastly, pop up windows are missing back buttons, which

	N	Minimum	Maximum	Mean	Std. Deviation
I think that I would like to use this system frequently	20	3	5	3.60	.681
I found the system unnecessarily complex.	22	1	4	1.41	.734
I thought the system was easy to use.	22	3	5	4.59	.590
I think that I would need the support of a technical person to be able to use this system.	22	1	5	2.14	1.320
I found the various functions in this system were well integrated.	19	2	5	3.95	.705
I thought there was too much inconsistency in this system.	20	1	3	1.40	.598
I would imagine that most people would learn to use this system very quickly.	22	2	5	4.27	.883
I found the system very cumbersome to use.	21	1	3	1.52	.750
I felt very confident using the system.	22	2	5	4.05	.999
I needed to learn a lot of things before I could get going with this system.	21	1	4	2.05	1.244

Table 12: SUS score for the Scenario Builder

	N	Minimum	Maximum	Mean	Std. Deviation
I think that I would like to use this system frequently	23	2	5	3.96	.976
I found the system unnecessarily complex.	25	1	4	2.04	.978
I thought the system was easy to use.	25	2	5	3.72	.891
I think that I would need the support of a technical person to be able to use this system.	25	1	4	2.48	1.194
I found the various functions in this system were well integrated.	25	3	5	4.24	.663
I thought there was too much inconsistency in this system.	25	1	4	1.80	.866
I would imagine that most people would learn to use this system very quickly.	25	3	5	3.84	.688
I found the system very cumbersome to use.	25	1	4	2.24	.831
I felt very confident using the system.	25	1	5	3.56	.917
I needed to learn a lot of things before I could get going with this system.	25	1	5	2.60	1.414

Table 13: SUS score for the Virtual Reality Scenario

force the user to commit to the module being added. For the VRS, it was indicated that the tool tip wording is inconsistent with the task list, having all the tool-tips appear at the start is overwhelming with many participants exclaiming "WOW" when first entering VR. Additionally, with over 100 drug vials to sort through, participants who are not familiar with the anesthesia cart had a very hard time finding the required vial. Furthermore, there was no audio feedback on making mistakes and this caused participants not to know they needed to pop the drug cap off the drug vial before attaching it to the syringe. Lastly, there were some bugs that caused tasks not to update accordingly, liquid did not fill the syringe when pulling, no vibration feedback for interactions, dialogue wheel wouldn't respond when selected, and the snap interaction would sometimes not trigger. However, these issues may have caused some participants to take longer than

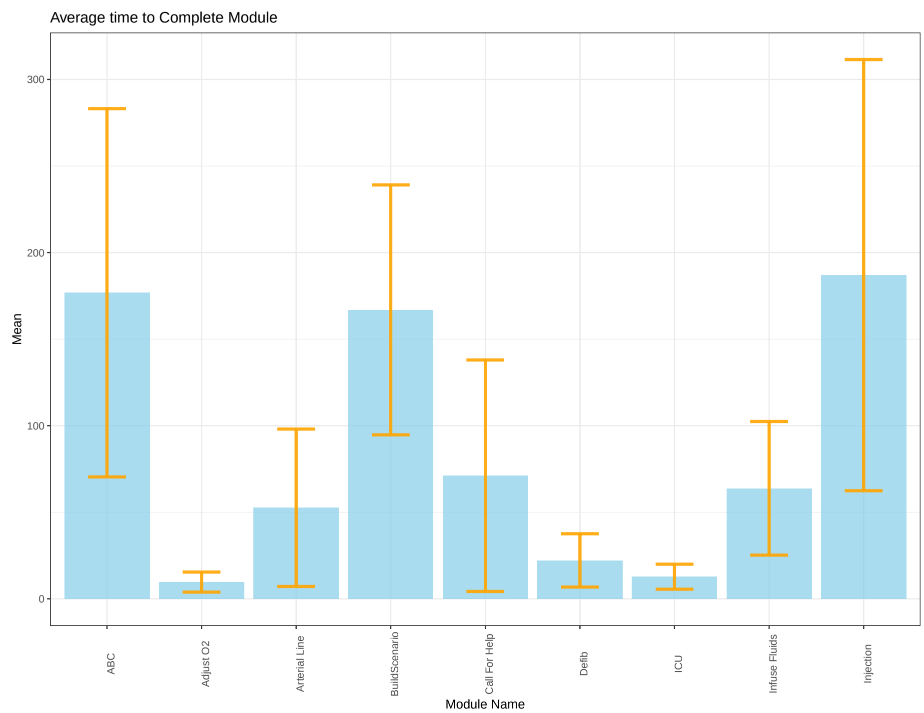

Figure 17: Average time to complete modules showing standard deviation

average when completing modules but it did not take away from participants enjoying themselves. All participants found themselves enjoying the VR portion of the ACSB as some participants stated "That was awesome". Additionally, some participants found that once they knew what they were doing it became easier to perform the modules. Many participants found themselves overwhelmed with the drug cart at first glance as the cart contained 100 or more drug vials when all they needed was one. Further frustration was added when the tool tip was not directly over the drug they selected as well the HTC Vive controller does not allow for precise grabbing with objects so small.

4.8 SUMMARY

In this section, I have discussed the usability study conducted on the ACSB, the usability issues discovered through the QUIS, SUS, and the open feedback portion of the questionnaire. The breakdown of the results was broken into two parts,

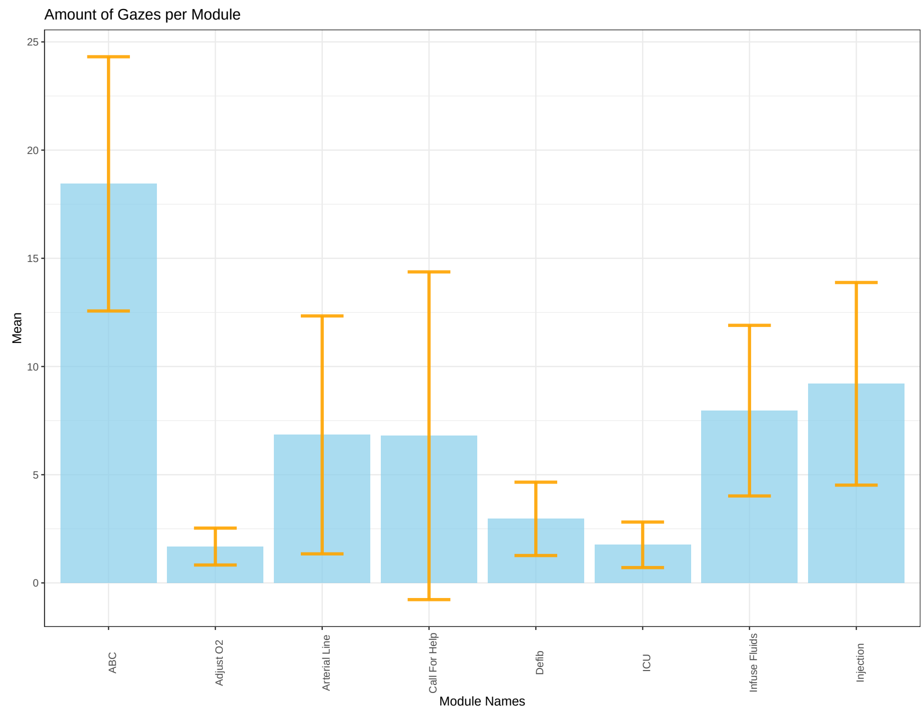

Figure 18: Average amount of gazes per module showing standard deviation

i) SB, and ii) VRS, this helped separate the issues discovered in both as well as allow for a better break down of the issues discovered through the questionnaire. Additionally, I have compared participants with a Computer Science background to participants with a Health Science background to see how they compare in terms of time to complete tasks and overall usability. It was shown that despite those with a Health Science background taking longer, they found the software more usable. Furthermore, the positive feedback that was received shows that the ACSB is usable in its current state, that there was enjoyment from using the framework and with further development could be a well-received tool.

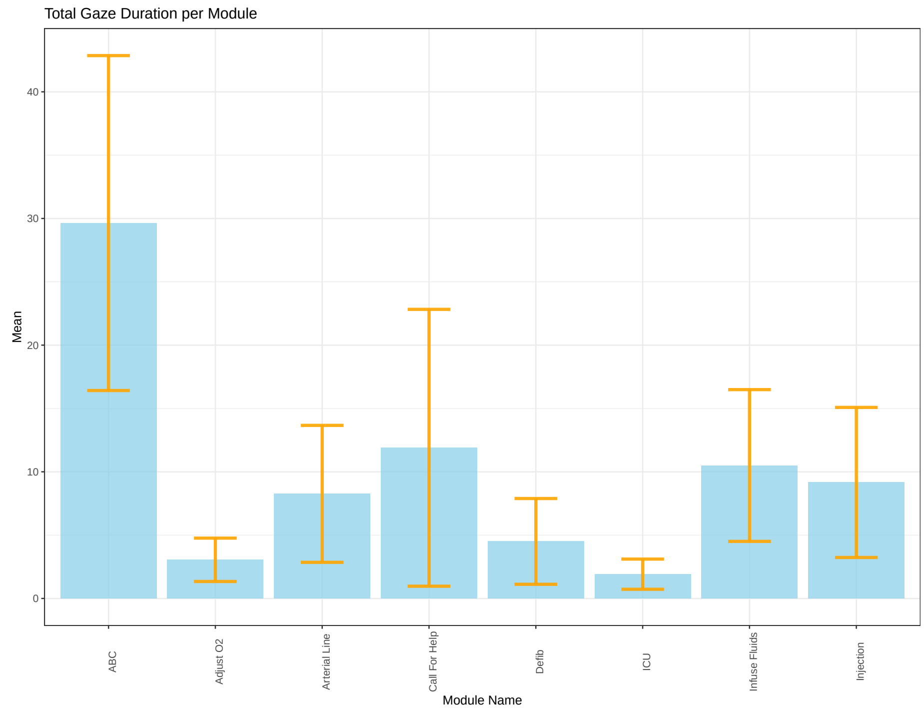

Figure 19: Average total duration of gazing per module showing standard deviation

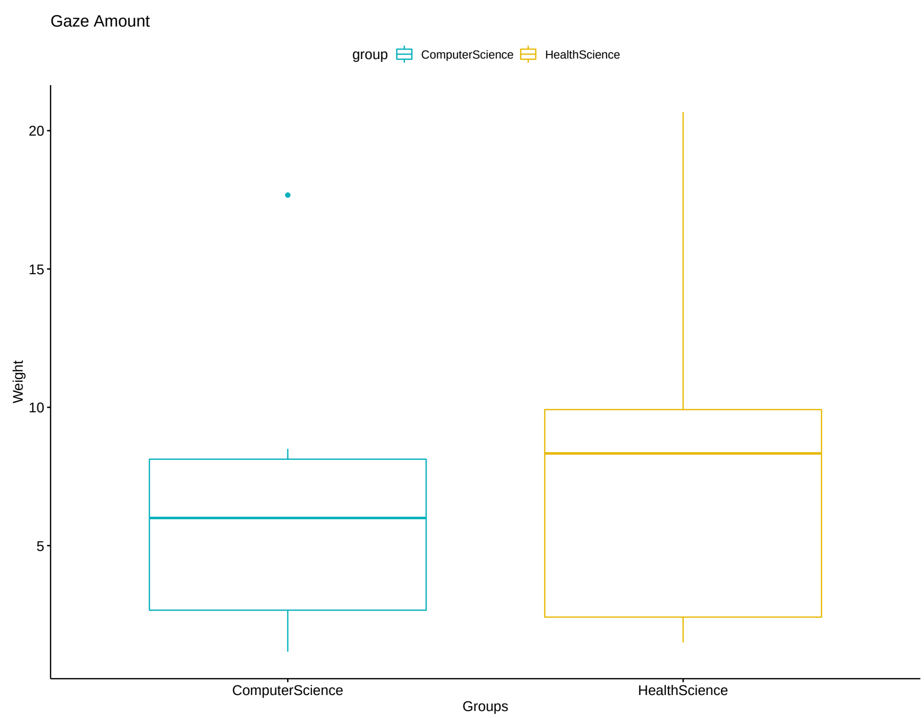

Figure 20: Comparison of Computer Science and Health Science student and the amount of times the task list was dialogued at.

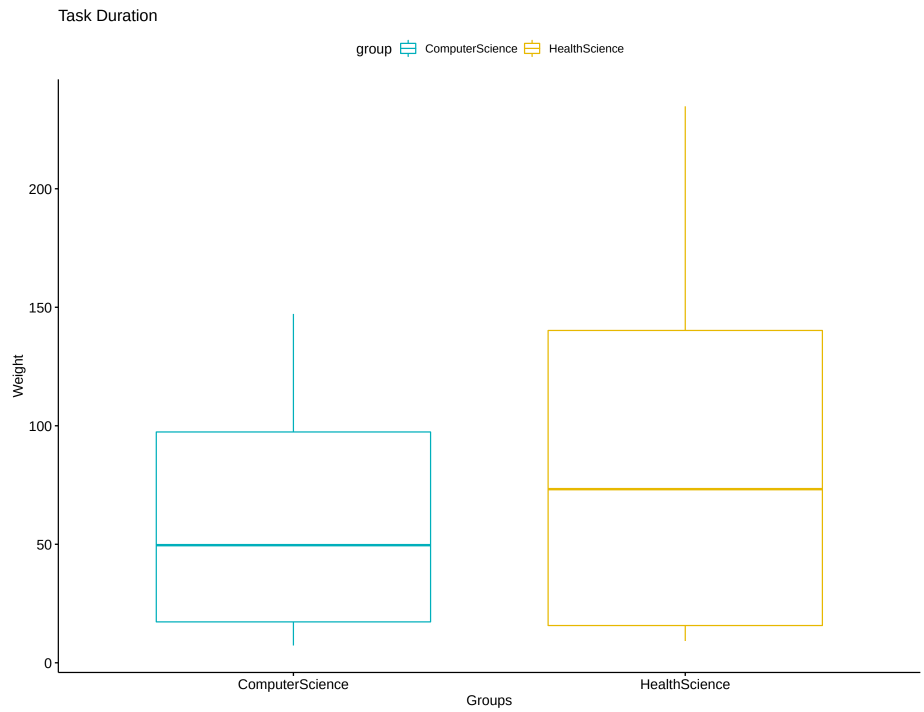

Figure 21: Comparison of Computer Science and Health Science student and the total time to complete the virtual scenario.

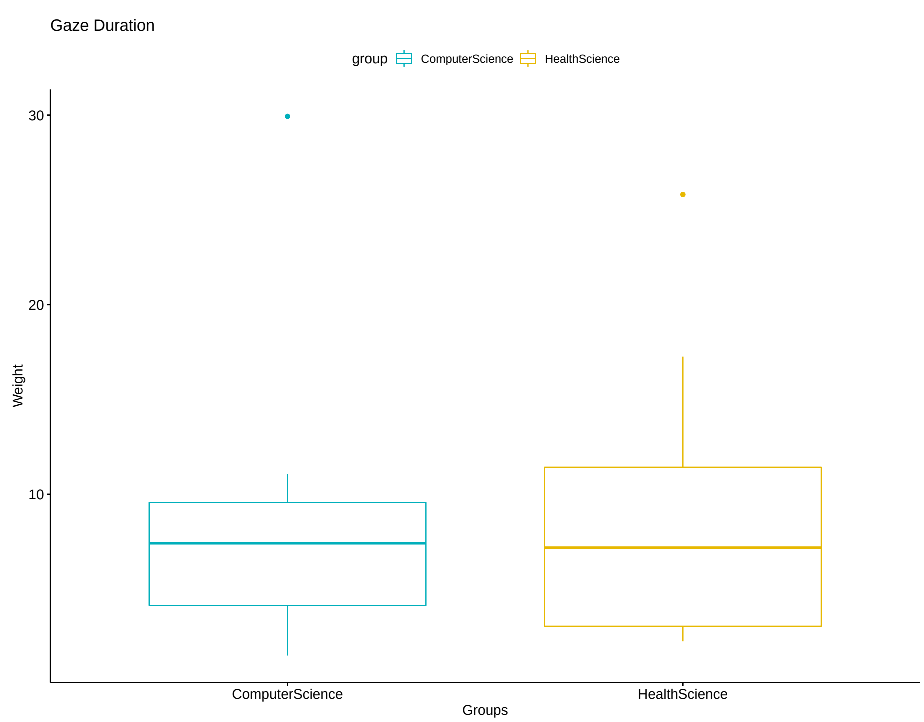

Figure 22: Comparison of Computer Science and Health Science student and the total time spent looking at the task list.

5 DISCUSSION

5.1 OVERVIEW

In this chapter, I will discuss the ACSB and how it fits into the simulation field as well as the virtual reality field in greater detail. Furthermore, I will discuss future improvements of the ACSB and how it will be tested with anesthesia residents/-trainees, and practicing anesthesiologists.

5.2 IMPLICATIONS ON SIMULATION, VIRTUAL REALITY & VIRTUAL SIMULATION

The ACSB demonstrates the benefits of virtual simulation and the potential of a consumer grade VR device. The results from the usability study showed that the ACSB was both engaging, well received by participants and easy to learn. Additionally, Health Sciences students (who participated in the study) without any VR experience were able to navigate the tool and complete the tasks effectively. Finally, the ACSB is the start of a longer-term initiative that will be continued to be developed and studied, and ideally it will be integrated into the anesthesia curriculum.

5.3 FUTURE WORKS

Despite the positive usability study results demonstrated here in addition to the fact that the ACSB was developed in close coordination with anesthesiologist Dr. Fahad Alam (Sunnybrook Health Sciences Centre in Toronto, Canada), the usability study has also provided insight regarding potential improvements to the

ACSB, More specifically, it was discovered that using the HTC Vive controllers to interact with the scene (e.g., using the syringe with one hand and drug vial with the other) was non-intuitive and problematic for most participants. The main issue with the syringe and drug vial interaction was related to the HTC Vive controllers which are much larger and clunkier than the objects being held (e.g., syringe and drug vial), making it awkward for most participants. Future work will examine improved and more natural (and intuitive) methods of interaction. Areas to be researched further include the use of VR gloves, adding cloud sharing for scenarios being built, more modules, and improving the study design. Each of these methods are described in greater detail below.

5.3.0.1 *VR Gloves*

Though VR controllers (e.g., the HTC Vive controllers as used in this work) may be the current method of interacting within VR, new and improved methods of interaction have recently become available. For example, devices such as the leap motion controllers[1] allows users to interact with their hands in the virtual environment by using the leap motion on the front of a HMDs. The leap motion controller works via cameras that detect the user's hands and creates a virtual pair of hands that can be used within the virtual environment. Additionally, to help combat the poor (un-natural) interactions within VR, future work will examine the use of VR Gloves which are a pair of gloves with embedded sensors that allow for the tracking of the fingers and hands position in virtual space. VR gloves allow the user to interact within the virtual environment with their own hands removing the inherent issues with controllers being too clunky. A controller being developed is the Valve Knuckle [2], which features hand tracking via sensors that are lined within the controller. The Valve Knuckle controller allows for more fluent motion and higher integration of hand controls that could assist in creating more realistic interactions that more closely resemble the real-world. However, it

1 https://www.leapmotion.com/
2 https://store.steampowered.com/valveindex

should be noted that having interactions that better match the real-world doesn't imply better performance or usability in the virtual world. Testing will have to be conducted to determine how effective these new interactions are.

5.3.0.2 *Scenario Sharing*

An additional feature that would further the capabilities of the ACSB is the ability to share scenarios and develop a repository where these scenarios can be kept and easily shared amongst various devices. The repository will also include an account management system (login ID and password) to allow and control multiple users requesting access to the repository to share scenarios. This will allow users to easily share the custom scenarios that they have created with the modules in the program to share with others.

5.3.0.3 *Module Extension*

A re-coding of the back end will be done based on the code structure of the Working at Heights (WAH) project mentioned in Chapter 3 as well as updating to the latest version of Unity and VRTK. Additionally, a dynamic patient system that allows for the controlling of heart rate, blood pressure, oxygen saturation, and other patient vitals that are required for an anesthesiologist will be developed and incorporated into the ACSB. Furthermore, a fail state into the scenario can be incorporated as currently you are given infinite amount of time to complete the scenario despite it being a crisis scenario where time is important. Future works will also examine the ethics of allowing a virtual patient to die and examine whether there are any positive or negative effects of doing so. This will help pave the way for additional modules to complete each task found within the Anesthesia Crisis Book [9]. Furthermore, the currently developed modules will be revisited and expanded upon on to better reflect the actual actions needed to take in real-life scenarios.

5.3.0.4 *Future Studies*

The usability study helped shed some light on various inconsistencies in item interactions and helped to highlight some quality of life features that were discussed previously that must be added to allow for a better experience and the flow between modules to be smoother. Once these features have been implemented, a usability study will be conducted with both practising anesthesiologists and trainees. This usability study will examine interactions that more closely reflect the real-world (as previously described) and terminology of the nurse/surgeon dialogue and description of the tasks. Finally, following the usability study, a user-based study will be conducted to examine the effectiveness of one (or multiple) modules/scenarios developed with the ACSB and more specifically, to quantify knowledge transfer and retention. This will involve pre- and post-testing with two groups, one group who uses the developed virtual simulator and another (the control group) who uses traditional training methods (and doesn't use the virtual simulators) that will look at learning, retention and cognitive skills.

5.4 SUMMARY

In this chapter, I discussed the ACSB and how it fits into virtual simulation and virtual reality. The ACSB though in its current stages is not replacing any educational tools; however through what is outlined in the future works and continued development of the ACSB, it shows how virtual simulation can create an immersive experience and provide trainees an additional training tool.

6 CONTRIBUTIONS & CONCLUSION

In this thesis, I have detailed the development of the ACSB a desktop/ VR application that allows for the creation and modification scenarios through the use of modules that make up the scenario. A usability study conducted with two groups of participants (those with a strong technical background (software development/programming ("coding") in particular), and those without) were generally positive indicating the potential of the ACSB as a tool for anesthesia training with a limited technical background. Furthermore, the results of the usability study provided details regarding areas of the ACSB that can be improved. The ACSB is a desktop/VR-based application that allows for a medical educator to create an anesthesia crisis scenario (in a simple manner and with a limited technical background). The developed virtual scenario allows trainees to go through it (i.e., complete the scenario), and develop their skills in an immersive and engaging manner.

It is important to reiterate and address the thesis statement:

> Does the ACSB allow for the simple creation of new scenarios or modification of existing ones without a strong technical background.

Despite the positive usability results that included above-average SUS and QUIS scores that indicate the ACSB was generally well received (i.e., it is "usable"), the ACSB currently has several usability issues and bugs that will be addressed in future works. Furthermore, improvements on the ACSB, and more specifically the SB, and improving the readability of the SB's user interface. With respect to the VRS, additional modules based on the ACM must be developed, and improvements will be made to the feedback provided by the modules, and to the interactions including their responsiveness. The ACSB can also be adjusted to fit into other categories laid out by Gardner [31], including surgical planning, patient experience and augmented reality-enhanced surgery. The ACSB could fit into surgical planning by allowing users to go into the VRS and create a mapping of where medical tools should be located in a crisis scenarios. The ACSB could also fit within patient experience by allowing patients to see inside an operating room and see where equipment and medical instruments are kept, how doctors perform certain surgeries, or even see the steps involved in a crisis scenario. The ACSB also fit into augmented reality- enhanced surgery by allowing doctors to see the steps they should be taking during a crisis scenario based on what is happening and guiding them to where the tools are located. Lastly, the body of work presented within this thesis and the developed ACSB could assist with creating a more learner-centered approach to learning about anesthesia crisis scenarios and general anesthesia procedures.

A

APPENDIX A: MODULE INFO

A.1 MODULE LIST

- Call For Help:

  Description: Call for help, communicate the problem and delegate

  - *Tell the Nurse to call for help*
  - *Tell the Surgeon to stop the surgery*

- Airway Breathing Circulation (ABC):

  Description: Cease all likely triggers, follow the ABC Guideline and commence CPR if indicated.

  Interaction: All

  - *Adjust O2 Knob by pressing the button on the monitor*
  - *Activate Airway Support by pressing the button on the monitor*
  - *Check Airway Pressure by looking at the monitor*
  - *Use a suction catheter to check for blockages*
  - *Check Patient Breathing by placing the stethoscope on the wrist*
  - *Check Monitor by looking at the monitor*
  - *Optional Commence CPR*

- *Adjust O2*: Description: Monitor the time, SoO2 and haemodynamics.

  Interaction: Button

  - *Interact with the monitor to cycle*

- *Infuse Fluids*: Description: Infuse fluids (at least 20ml/kg) and elevate the legs

  Interaction: Snap Object

  - *Attach IV Bag to stand*
  - *Attach the connector to IV Bag*

- *Injection*: Description: Give intravenous <Drug Name> _ mcg/kg in bolus doses. If cardiovascular collapse use _ mg.

  Interaction: Interact

– *Using a syringe inject the patient with:*

- *Arterial Line*: Description: Insert an arterial line for monitoring and gases as soon as possible - delegate if necessary.

  Interaction: Snap Object

  - *Attach the arterial line piece 1 to the patients wrist*
  - *Attach the arterial line piece 2 to arterial line piece 1*

- *Adjunctive Therapy*: Description: Give <Drug_Name>.

  Interaction: Interact

– *Using a syringe inject the patient with:*

- *Defib*: Description: Shock em.

  Interaction: Gaze

  - *Inform the Nurse to defibrillator the patient with a certain amount of joules*

- *ICU*: Description: Move patient to ICU.

  Interaction: Gaze

  - *Inform the Nurse to move the patient to the ICU*

B

APPENDIX B: QUESTIONNARIE

B.1 QUESTIONNARIE PART 1

Survey Part 1

* Required

1. **My age is:**

____

2. **My gender is:** *

Mark only one oval.

- ( ) Female
- ( ) Male
- ( ) Prefer not to say
- ( ) Other: ______________________

3. **Select the faculty you belong to.**

Mark only one oval.

- ( ) Faculty of Business and Information Technology
- ( ) Faculty of Health Sciences
- ( ) Faculty of Science
- ( ) Faculty of Education
- ( ) Faculty of Engineering and Applied Science
- ( ) Faculty of Energy Systems and Nuclear Science
- ( ) Faculty of Social Science and Humanities

4. **Do you have any Virtual Reality Experience.**

Mark only one oval.

- ( ) Yes
- ( ) No

5. **What part of the project did you just complete.** *

Mark only one oval.

- ( ) Scenario Builder
- ( ) Virtual Reality Scenario

6. **What did you call the Scenario?** *

____

Overall reactions to the software:

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

7. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
terrible											wonderful

8. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
frustrating											satisfying

9. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
dull											stimulating

10. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
difficult											easy

11. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
inadequate power											adequate power

12. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
rigid											flexible

Screen

Select the number which most appropriately reflects your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

13. **Characters on the computer screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
hard to read											easy to read

14. **Image of characters**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
fuzzy	○	○	○	○	○	○	○	○	○	○	sharp

15. **Character shapes (fonts)**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
barely legible	○	○	○	○	○	○	○	○	○	○	very legible

16. **Highlighting on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	○	○	○	○	○	○	○	○	○	○	helpful

17. **Use of reverse video**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	○	○	○	○	○	○	○	○	○	○	helpful

18. **Use of blinking**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	○	○	○	○	○	○	○	○	○	○	helpful

19. **Use of bolding**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	○	○	○	○	○	○	○	○	○	○	helpful

20. **Screen layouts were helpful**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	○	○	○	○	○	○	○	○	○	○	always

21. **Amount of information that can be displayed on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

22. **Arrangement of information on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
illogical	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	logical

23. **Progression of work related tasks**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clearly marked

Terminology and System Information

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

24. **Use of terminology throughout system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

25. **Work related terminology**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

26. **Computer terminology**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

27. **Terminology relates well to the work you are doing?**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

28. **Computer terminology is used**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too frequently	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	appropriately

29. **Terminology on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
ambiguous	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	precise

30. **Messages which appear on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

31. **Position of instructions on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

32. **Messages which appear on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

33. **Instructions for commands or functions**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

34. **Instructions for correcting errors**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

35. **Computer keeps you informed about what it is doing**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

36. **Performing an operation leads to a predictable result**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

37. **Controlling amount of feedback**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
impossible	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

38. **Length of delay between operation**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unacceptable	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	acceptable

Learning

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

39. **Learning to operate the system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

40. **Getting started**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

41. **Learning advanced features**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

42. **Time to learn to use the system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
slow	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	fast

43. **Exploration of features by trial and error**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
discouraging	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	encouraging

44. **Exploration of features**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
risky	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	safe

45. **Discovering new features**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

46. **Remembering names and use of commands**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

47. **Remembering specific rules about entering commands**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

48. **Tasks can be performed in a straight-forward manner**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

49. **Number of steps per task**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too many	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	just right

50. **Steps to complete a task follow a logical sequence**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

51. **Feedback on the completion of the steps**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unclear	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

System Capabilities

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

52. **System speed**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too slow	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	fast enough

53. **Response time for most operations**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too slow											fast enough

54. **Rate information is displayed**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too slow											fast enough

55. **The system is reliable**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never											always

56. **Operations are**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
undependable											dependable

57. **System failures occur**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
frequently											seldom

58. **System warns you about**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never											always

59. **System tends to be**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
noisy											quiet

60. **Mechanical devices such as fans, disks, and printers**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
noisy	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	quiet

61. **Computer generated sounds are**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
annoying	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	pleasant

62. **Correcting your mistakes**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

63. **Correcting typos**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
complex	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	simple

64. **Ability to undo operations**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

65. **Ease of operation depends on your level of experience**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

66. **You can accomplish tasks knowing only a few commands**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

67. **You can use features/shortcuts**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
with difficulty	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easily

Technical Manuals and On-line Help

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

68. **Technical manuals are**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

69. **The terminology used in the manual**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

70. **Information from the manual is easily understood**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

71. **Finding a solution to a problem using the manual**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
impossible	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

72. **Amount of help given**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	adequate

73. **Placement of help messages on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

74. **Accessing help messages**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

75. **Amount of help given**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

76. **Help defines specific aspects of the system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

The System Usability Scale

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

77. **I think that I would like to use this system frequently**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

78. **I found the system unnecessarily complex.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

79. **I thought the system was easy to use.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

80. **I think that I would need the support of a technical person to be able to use this system.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

81. **I found the various functions in this system were well integrated.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

82. **I thought there was too much inconsistency in this system.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

83. **I would imagine that most people would learn to use this system very quickly.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

84. **I found the system very cumbersome to use.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

85. **I felt very confident using the system.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

86. **I needed to learn a lot of things before I could get going with this system.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

87. **Open:**
Provide any comments/feedback not necessarily covered in the previous questions.

B.2 QUESTIONNARIE PART 2

Survey Part 2

* Required

1. **What part of the project did you just complete.** *
   Mark only one oval.
   - ( ) Scenario Builder
   - ( ) Virtual Reality Scenario

2. **What did you call the Scenario?** *

   ____

Overall reactions to the software:

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

3. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
terrible	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	wonderful

4. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
frustrating	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	satisfying

5. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
dull	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	stimulating

6. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
difficult	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	easy

7. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
inadequate power	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	adequate power

8. *Mark only one oval.*

	0	1	2	3	4	5	6	7	8	9	
rigid	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	flexible

Screen

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

9. **Characters on the computer screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
hard to read	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy to read

10. **Image of characters**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
fuzzy	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	sharp

11. **Character shapes (fonts)**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
barely legible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	very legible

12. **Highlighting on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	helpful

13. **Use of reverse video**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	helpful

14. **Use of blinking**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	helpful

15. **Use of bolding**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unhelpful	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	helpful

16. **Screen layouts were helpful**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

17. **Amount of information that can be displayed on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

18. **Arrangement of information on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
illogical	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	logical

19. **Progression of work related tasks**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clearly marked

Terminology and System Information

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

20. **Use of terminology throughout system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

21. **Work related terminology**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

22. **Computer terminology**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	consistent

23. **Terminology relates well to the work you are doing?**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

24. **Computer terminology is used**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too frequently	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	appropriately

25. **Terminology on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
ambiguous	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	precise

26. **Messages which appear on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

27. **Position of instructions on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inconsistent	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	consistent

28. **Messages which appear on screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

29. **Instructions for commands or functions**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

30. **Instructions for correcting errors**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	clear

31. **Computer keeps you informed about what it is doing**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

32. **Performing an operation leads to a predictable result**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

33. **Controlling amount of feedback**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
impossible	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

34. **Length of delay between operation**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unacceptable	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	acceptable

Learning

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

35. **Learning to operate the system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

36. **Getting started**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

37. **Learning advanced features**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

38. **Time to learn to use the system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
slow	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	fast

39. **Exploration of features by trial and error**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
discouraging	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	encouraging

40. **Exploration of features**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
risky	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	safe

41. **Discovering new features**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

42. **Remembering names and use of commands**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

43. **Remembering specific rules about entering commands**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

44. **Tasks can be performed in a straight-forward manner**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

45. **Number of steps per task**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too many	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	just right

46. **Steps to complete a task follow a logical sequence**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

47. **Feedback on the completion of the steps**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unclear	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

System Capabilities

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

48. **System speed**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too slow	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	fast enough

49. **Response time for most operations**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too slow	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	fast enough

50. **Rate information is displayed**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
too slow	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	fast enough

51. **The system is reliable**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

52. **Operations are**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
undependable	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	dependable

53. **System failures occur**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
frequently	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	seldom

54. **System warns you about**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	always

55. **System tends to be**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
noisy	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	quiet

56. **Mechanical devices such as fans, disks, and printers**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
noisy	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	quiet

57. **Computer generated sounds are**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
annoying	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	pleasant

58. **Correcting your mistakes**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	easy

59. **Correcting typos**

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
complex	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	simple

60. **Ability to undo operations**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

61. **Ease of operation depends on your level of experience**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

62. **You can accomplish tasks knowing only a few commands**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

63. **You can use features/shortcuts**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
with difficulty	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easily

Technical Manuals and On-line Help

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

64. **Technical manuals are**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

65. **The terminology used in the manual**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

66. **Information from the manual is easily understood**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	always

67. **Finding a solution to a problem using the manual**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
impossible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

68. **Amount of help given**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

69. **Placement of help messages on the screen**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
confusing	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	clear

70. **Accessing help messages**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
difficult	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	easy

71. **Amount of help given**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

72. **Help defines specific aspects of the system**
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
inadequate	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	adequate

The System Usability Scale

Select the number which most appropriately reflect your impressions of using the software or system.
You can skip the item if you believe that it is not applicable.

73. **I think that I would like to use this system frequently**

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

74. **I found the system unnecessarily complex.**

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

75. **I thought the system was easy to use.**

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

76. **I think that I would need the support of a technical person to be able to use this system.**

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

77. **I found the various functions in this system were well integrated.**

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

78. **I thought there was too much inconsistency in this system.**

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

79. **I would imagine that most people would learn to use this system very quickly.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

80. **I found the system very cumbersome to use.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

81. **I felt very confident using the system.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

82. **I needed to learn a lot of things before I could get going with this system.**
Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

83. **Open:**
Provide any comments/feedback not necessarily covered in the previous questions.

B.3 TASK LIST

For this study, you will be creating a scenario from scratch and running through the scenario in VR. When you are ready please hit the play button within the Unity Editor found at the top middle of the unity project.

1. Please re-create the scenario below creating a new model and giving its name and description of your choosing. Then by clicking add module to add the modules.
2. Select the Run Scenario option found under the File option.
3. Open this link and fill out the survey before going into virtual reality.
4. Put on the Virtual Reality Equipment AND headphones and follow the scenario you built.
5. Open this link and fill out the survey.

CallHelp	Gaze	N/A	
ABC	Interact	is CPR Needed	
Defib	Interact	Amount	J300
AdjustO2	Button	N/A	
InfuseFluids	Snap Object	N/A	
Injection	Interact	Injection	Dexamethasone
ArterialLine	Snap Object	N/A	
ICU	Gaze	N/A	

At any time you can ask for assistance.

B.4 CONSENT FORM

UOIT
CHALLENGE INNOVATE CONNECT

Usability Testing of a Virtual Reality-based Anesthesia Crisis Scenario Builder

Participant Consent Form

The last four years have seen the re-introduction and rising popularity of virtual reality devices, namely head-mounted displays (HMDs). These are stereoscopic displays which a user wears on their head, allowing them to view into and interact within a 3D virtual reality environment. While the traditional videogame industry has been quick to adopt the new popularity of virtual reality devices, very little modern progress and minimal research on the use of these devices in real-world applications is currently available. Although the potential of these devices is apparent to those who have used them and seen them in action, their use to improve traditionally desktop-based tasks is currently unexplored. We have developed an anesthesia scenario builder which asks the user to prepare a scenario and run through the modules they selected within a virtual operating room.

I (please print your participant number here), participant number _____ understand that I have been invited to participate in a usability study. Participation involves sharing myself using the epidural preparation tool (where I will navigate through and manipulate objects within a virtual room), for two 5 minute sessions within the HTC Vive virtual reality device, which is a consumer-grade device available to the general public. After each of these 5 minute game-play sessions, I will complete an electronic questionnaire (via Google Doc) that will ask me questions regarding the game itself and more specifically, its graphics, sound, interaction, and usability. These graphics include the general visual look of the game, elements of the user interface and objects within the virtual environment. Finally, I will be part of a debriefing period where I may ask any additional questions to the experimenter. I also understand that as a participant in this experiment, I am not waiving my legal rights. The experiment will take approximately 35 minutes to complete.

At any time during the experiment, I am aware that I may decline to answer a question and may withdraw from the research altogether at any point for whatever reason without explaining any reasons and without any consequence. There won't be any penalty or negative consequence for students who withdraw from the study. I may also choose to withdraw after completing the survey. If I choose to withdraw, I may do so by letting the experimenter know that I wish to withdraw either verbally, through email, or any other communication means. If my survey data has not been submitted (i.e., I have not completed the survey), the experimenter will close the browser window containing the survey, thus eliminating any responses. If I choose to withdraw from the experiment after completing (submitting) my responses, the experimenter will remove the data (via my participant number) from Google Doc at a later time. I must exercise my withdrawal right within 90 days of the experiment if I choose to do so, as the anonymized data will be used as a part of ongoing work.

I understand that the experiment will be conducted by a graduate student working under the supervision of Dr. Bill Kapralos and any information collected will be used to develop a thorough understanding of the tool, including any necessary revisions needed, future development considerations and integration within a curriculum. I understand that the sessions will not be video or audio recorded and my name will be removed from any collected data to maintain anonymity. All data will be kept by Dr. Bill Kapralos on his computer and backed-up on a hard disk that is accessed only by Dr. Bill Kapralos and stored in a secure filing cabinet. Risks in this study involve minor visual discomfort or motion sickness as I may be using a virtual reality device. Furthermore, wearing the virtual reality device and walking around a small open area may lead to coming into contact with the walls of the experimental room. Every effort will be made on behalf of the facilitators to ensure that I am using the device properly to minimize the chance of visual discomfort or motion sickness. The virtual reality device itself, as well as the experimenter, will ensure that the risk of coming into contact of any walls while wearing the device is minimized. Every effort will also be made on behalf of the facilitators to avoid any invasion of my privacy. If I find the information obtained from this experiment interesting I can request a copy of the final report from the researchers at any time.

I further agree that my anonymized data may be used in future work not relating directly to this study (a Secondary Use of Data).

If you have any questions concerning the research study or experience any discomfort related to the study, please contact the researcher Kyle Wilcocks at 905.721.8668 x. 2882 or kyle.wilcocks@uoit.ca.

Any questions regarding your rights as a participant, complaints or adverse events may be addressed to Research Ethics Board through the Ethics and Compliance Officer - researchethics@uoit.ca or 905.721.8668 x. 3693.

This study has been approved by the UOIT Research Ethics Board REB #14-129 on October 16th, 2016.

I agree to participate in this study and will keep a copy of this consent form for my personal records.

Experimenter: Kyle Wilcocks
Principal Investigator: Dr. Bill Kapralos

Participant Signature:____________________________, Date:___________________
Witness (Experimenter) Signature:__________________, Date:___________________

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Bernard, Christopher Oxen, Kyle Johnsen, Robert Dickerson, A Raji, B Lok, M Cohen, L Schumacher, J Garrett Harper, D Scott Lind, and College Georgia. ABSTRACT # 1365 - POSTER BOARD # 31 Trauma Simulation Drills in the Resuscitation Unit : The Challenge of Teams ABSTRACT # 1371 - POSTER BOARD # 1 A Multi-Institutional Pilot Study to Evaluate the Use of Virtual Patients to Teach Health Professions Studen. pages 92–143.