A Comparison of Seated and Room-Scale Virtual Reality on Medical-Based Serious Games and Virtual Simulation

by

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Abstract

Simulation-based training has been widely adopted by healthcare education as a vital tool in the practice of skills within a safe environment. However, significant cost and logistical challenges exist within traditional simulation practices. Serious games, or games with a primary purpose other than entertainment, are virtual simulations which can address many of these issues while remaining proven tools for effective skills transfer to the real world. This thesis presents two serious games for anesthesia training, one dealing with anesthesia crisis resource management skills and one serving as an epidural procedure preparation tool. The work seeks to demonstrate that the combination of serious games and consumer-grade virtual reality hardware provide an interactive and engaging simulation environment for anesthesia training. Through a set of usability tests, results indicate that both serious games offer a level of game engagement while demonstrating the ability of room-scale virtual reality to provide certain benefits applicable to serious games and simulations. From this, a set of recommendations and guidelines for the designers and developers of serious games and simulations are provided.

KEYWORDS: anesthesia, serious games, simulations, virtual reality

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Acronyms

ACLS Advanced Cardiovascular Life Support.

ACRM Anesthesia Crisis Resource Management.

CRM Crew Resource Management.

GDE Game Development and Entrepreneurship.

GEQ Game Engagement Questionnaire.

HMD Head mounted display.

IPD Interpupillary distance.

QUIS Questionnaire for User Interface Satisfaction.

SUS System Usability Scale.

UI User interface.

UOIT University of Ontario Institute of Technology.

VR Virtual reality.

Chapter 1

Introduction

1.1 Overview

This thesis describes the use of serious games and consumer-grade room-scale virtual reality to provide an interactive and engaging simulation environment for anesthesia training. In this chapter I discuss the gaps which currently exist in anesthesia skills training and how they may be addressed with the use of consumer-grade virtual reality devices and serious games. Specifically, I describe the falling confidence of anesthesiology trainees and the impact this has on their ability to adapt relevant knowledge and skills to ever-changing situations. Virtual simulation in the form of serious games can address these issues by providing an interactive and engaging learner-centric approach to education which takes into account each individual trainee's own pace of instruction. These factors form the basis of my thesis statement which I use to develop two separate serious games; one for anesthesia training and one for investigating the effect of different VR room configurations. Finally, in the following sections, I summarize the contributions of this thesis before beginning a chapter on related work.

1.2 Motivation

Through significant organizational changes to the training programs of anesthetists, trainee confidence is falling despite changes in working patterns and reduced working hours over the past decade [62]. Furthermore, traditional teacher-centric approaches to instruction may be failing due to a different generation of trainees accustomed to an alternate style of teaching with immediate mobile access to information on Internet-connected devices. Instead, a learner-centric approach to education whereby the learner can approach the content according to their own style and with their own background knowledge in mind may prove necessary [57]. As stated by Smith et al.

during a 2011 survey of attitudes to excellence among UK anesthesia trainers, "The achievement of excellence in anaesthesia is likely to depend on the successful interplay of individuals' personal qualities and the environment in which they work" [104].

To facilitate this learner-centric approach to anesthesia training I have focused my work on the joint application of serious games and virtual reality to this cause. Current training is generally implemented as "a package of direct teaching, targeted supervision, and overall experience of the knowledge, skills, and attitudes essential to the safe and effective delivery of anaesthesia" [62]. This includes the use of in-class simulation, which although may prove effective, incurs substantial cost and logistical challenges [36, 63]. Instead, virtual simulation can overcome many of these limitations by proving a cost-effective learner-centric approach to anesthesia education [50]. Software deployable across multiple trainee devices combined with a reduced need for expensive physical simulators and analogues, for example, result in a reduction in training costs despite remaining effective. In an analysis of 606 articles relating to health professions education, Cook et al. found that technology-enhanced simulation training in health professions education is "consistently associated with significant effects on the outcomes of knowledge, skills, and behaviors and with moderate effects on patient-related outcomes compared to no intervention" [19, 15]. The rising popularity of video games has seen a recent push towards the application of video game-based technologies, and serious games in particular (that is, games whose primary purpose extends beyond entertainment), to teaching and learning. This, coupled with the growing popularity and availability of consumer-grade virtual reality VR devices presents incredible opportunities for teaching skills and competencies within a specific specialty [33, 39, 78].

The historical use of VR within various domains of teaching has largely been specialized and expensive. However, during the last two to three years, several high-quality, affordable consumer-grade VR devices have become widely available [53, 89, 114, 45]. One such VR device is the HTC Vive, a system incorporating a motion-tracked headset and pair of hand controllers for use with a personal computer [44]. Despite the growing popularity of gaming- and VR-based technologies to education and training, before these technologies become more widespread, there are a number of problems and questions that must be addressed. One problem includes which specific VR setup (seated, standing, or room-scale) is best. Seated VR denotes a seated and stationary user within a small motion-tracked space, standing VR includes a standing but stationary user within a larger space, and finally room-scale VR allows the user to physically walk around within a large motion-tracked space. Although this thesis focuses on the general application of VR with respect to serious games for anesthesia training, I also specifically investigate which VR system setup should be used (seated, room-scale, or standing). This is important due to the implications of each: i) seated VR requires the smallest amount of room to use and is supported by a larger number of cheaper devices, ii) room-scale VR is exclusive to the most expensive of devices and requires the largest amount of room to use, and iii) standing VR may be a middle-ground option between the two yet sacrifice some of the benefits of each.

1.3 Thesis Statement

> *The combination of serious games and consumer-grade virtual reality hardware provide a usable, interactive, and engaging simulation environment for anesthesia training.*

This thesis documents the design, development, and usability testing of two serious games that I have created within multi-disciplinary teams of software developers and medical experts. The aim of this thesis is two-fold: i) to demonstrate that serious games for anesthesia training are a usable, interactive, and engaging tool for anesthesia education, and ii) to compare the effect of room-scale virtual reality as compared to seated virtual reality and to discuss the implications this may have to such serious games.

1.4 Contributions

This thesis provides the following contributions to the field of Computer Science and more specifically the area of serious games and virtual reality for health professions education:

- *ACLS serious game*: A desktop-based serious game was developed to train Anesthesia Crisis Resource Management (ACRM) skills. More specifically, the Advanced Cardiovascular Life Support (ACLS) clinical intervention for the urgent treatment of cardiac arrest, stroke and other life-threatening medical emergencies. The serious game provides a way for a trainee to interactively react to a simulated medical emergency within a virtual operating room environment. This affords a safe, repeatable, and widely scalable learner-centric teaching tool for anesthesia training.

- *Five recommendations for general serious games development*: The results of experiments described in Chapter 3 led to the development of five recommendations intended for designers and developers of serious games: i) work in an interdisciplinary team, ii) strive for graphical and audio realism as the project requires, iii) aim to include usability options for the most commonly performed tasks, iv) design trainee interactions around standardized controls which they may be familiar with, and v) prioritize usability testing early in the project to uncover the most common issues interfering with a trainee's engagement with the game.

- *Epidural procedure preparation serious game*: An HTC Vive VR-based serious game was developed to teach epidural procedure preparation skills within a virtual environment. The serious game allows for seated, standing, and room-scale VR setups.

- *Increased understanding of the benefits of room-scale VR compared to seated VR*: The results of experiments described in Chapter 4 showed four significant differences between seated and room-scale VR implementations of the same serious game: i) increased overall positive reactions to the usability of the system, ii) increased user immersion, iii) shorter task completion times during tasks which combined different interaction types (moving the virtual avatar and transporting held objects), and iv) greater 3D spatial precision during held object placement.

- *Five recommendations and three guidelines for serious games developers who wish to employ consumer-grade VR devices*: The results of experiments described in Chapter 4 led to the construction of five recommendations and three guidelines which serious games designers and developers should follow. The recommendations include: i) work in an interdisciplinary team, ii) allow for explorable interactions based upon motion controls, iii) provide ambidextrous controls, iv) strive for graphical and audio realism as the project requires, and v) work around system limitations with respect to system performance and the capabilities of the VR hardware. The three guidelines drawn from experimental data include: i) prefer room-scale VR if appropriate for the project, ii) utilize motion controls if possible, and iii) combine different types of VR interactions together.

1.5 Organization

The remainder of the thesis is organized as follows:

- Chapter 2: An overview of the historical use of traditional and virtual simulation, virtual reality, and serious games with respect to healthcare is provided. More specifically, I briefly discuss the role of simulation within anesthesia training. In addition, my own previous work with serious games and simulations is detailed and their role in forming the motivation for the work outlined in this thesis is addressed.

- Chapter 3: An initial usability study of a serious game for advanced cardiovascular life support skills is provided. The game's development is described before an explanation of the study methodology and results is provided. This chapter contributes a set of guidelines for the designers and developers of serious games.

- Chapter 4: An initial usability study of a serious game for epidural procedure preparation is provided. The study was designed to investigate the effect of different virtual reality system setups with respect to serious games, and the study results are explained in detail. This chapter contributes a set of guidelines for the designers and developers of serious games who wish to incorporate modern consumer-grade virtual reality devices into their applications.

- Chapter 5: The results of both studies are discussed and their implications on traditional and virtual simulation, virtual reality, and serious games are detailed. Suggestions for possible future work are provided before concluding with this thesis' contributions.

Chapter 2

Related Work

2.1 Overview

In this chapter, I provide an overview of the concepts and relevant previous work in the areas of traditional and virtual simulation, virtual reality, anesthesia simulation training, and serious games. I begin by describing simulation, the immersion of a trainee within a specific situation which replicates a real-world scenario. This includes the history of simulation, how it is used extensively within healthcare, and the benefits it provides. This transitions into a discussion of virtual simulation and how it overcomes some of the limitations of traditional simulation, and insight towards modern advances with respect to consumer-grade virtual reality. Anesthesia simulation-based training is specifically mentioned, as the primary contribution of this thesis consists of a serious game for anesthesia skills training. The use of video game concepts with respect to teaching in the form of serious games is also explained, and key concepts of these games useful to their developers is outlined. Finally, I discuss the previous serious games that I have developed and their impact on forming the direction of the work described in this thesis.

2.2 Simulation

Many of the modern advances in serious games and virtual reality (VR) stem heavily from a long history of traditional simulation. Summarized by Dubrowski et al. [27], simulation involves immersion of the trainee in a realistic situation (scenario) created within a physical or virtual space (simulator) that replicates the real environment [42]. In the context of health professions education (HPE), simulation can be defined as an education technique that allows interactive and immersive activity by recreating all or part of a clinical experience without exposing patients to associated risks [76]. This can include a wide variety of tools and processes, devices, technologies, computer programs and virtual spaces, scenarios, and standardized patients to imitate real-world environments and situations [25]. This imitation of real-world processes is widely used for the practice of skills, problem solving, and judgment which mirror real-world situations and environments. As noted by Gaba and DeAnda, simulators provide many advantages in educational contexts and supply learning opportunities in situations that are unsafe, unethical, or otherwise impractical in the real world [36]:

- No risk to others involved in the situation, such as hospital patients.
- Scenarios involving uncommon but serious problems can be presented.
- The same scenario can be presented sequentially to multiple subjects.
- Errors can be allowed (and often times encouraged) although in a real setting such errors would require immediate intervention by a supervisor.
- If desired, the simulation may be halted for a teaching moment and can be restarted to demonstrate different techniques.
- Recording, replay, and post-simulation critique of performance can be facilitated.

Traditional simulation has been used extensively in fields which require both vigilance and the ability to react quickly to life-threatening situations, such as in aviation, ship-handling, or nuclear power [85, 38, 116, 120]. In fact, The Link Trainer was the first simulator developed for recreational flight pilot training during the 1930s [106]. The Link Trainer's ability to replicate an aircraft's rotations, movements, and instruments in a safe environment led to its adoption by the United States Army only six years later in 1934 (see Figure 2.1). With the increased military needs of World War II, aviation simulation experienced a tremendous growth after the introduction of the Link Trainer to include other uses such as the simulation of various NASA-based missions, including the Apollo moon missions. Citing pilot safety and overall savings in training costs, simulation was adopted on a large scale basis for other uses including medical education [125, 108].

Figure 2.1: A 1942 Model C-3 Link Trainer restored by the Western Museum of Flight, California, United States [106].

To discuss simulation in healthcare it is necessary to mention David Gaba, a pioneer of the field and one of the first within the community to develop, use, and test simulation-based training in healthcare applications. Focusing on anesthesia administration, patient monitoring, and intervention, Gaba and DeAnda developed CASE, the Comprehensive Anesthesia Simulation Environment in 1988 [36]. It was the first full-scale simulator that recreated the working environment of an operating room. Subjects performed both manual and cognitive tasks within the operating room using a combination of custom and standard monitoring equipment, with capabilities for invasive and non-invasive monitoring of a mannequin. Conducted by a systems operator behind the scene and a simulation director filling the role of surgeon and circulating nurse, a pre-scripted scenario dictated the monitoring equipment's outputs to be assessed and responded to by the subject. With over 20 scenarios that could be simulated, both life-threatening and non-life-threatening, their initial results from 21 subjects were promising. Responding in opinion that the simulation was considered very realistic, CASE became a foundation for the future success of scenario-based simulation being used for healthcare training purposes. In addition to anesthesia training, simulators have been developed for a wide variety of surgical specialties, such as ophthalmology, orthopedics, vascular intervention, endoscopy, and laparoscopy [86, 40, 124].

Although simulation based training has been widely adopted as a part of health professions education, significant and increasing set up, fixed per-year and variable per-course hour costs raise a prohibitive barrier of entry. Although CASE was able to be developed on a small budget of approximately USD $18,000 in the late 1980's, the increased sophistication of simulators has led to a corresponding increase in cost [36]. In a study of their own simulation centre in 2006, McIntosh et al. found initial set up costs (facility renovation, equipment) exceeded USD $870,000, while fixed per-year costs exceeded USD $360,000 [63]. Including variable per-course hour costs of USD $311, they recommend that economic viability of simulation centres depends on the number of billable hours taught per week as well as co-operation and sharing of resources between separate centres. The exponential rise and adoption of simulation centres despite these high costs displays the belief and support of educators and institutions towards innovative, non-traditional learner-centric approaches to education.

2.3 Virtual Simulation and Virtual Reality (VR)

While simulation-based teaching methods have proven to be effective, virtual simulation in particular offers distinct benefits of its own that may overcome the limitations of traditional simulation. Virtual simulation replicates real-world situations, scenarios, locations, or processes (similar to traditional simulation) through the use of immersive technologies. Virtual simulators may come in the form of software packages deployed on desktop computers, mobile devices, or specialized hardware, and may also be paired with physical technologies such as haptic input devices, touch-table computers, and virtual reality headsets. Some of the proposed benefits of virtual simulation include [50]:

- *Reduced Cost*: Training using virtual simulation can be accomplished at a lower cost than existing methods of training. For example, simulation with the use of cadavers or human analogues is costly (up to USD $5,000 each) and require specialized facilities and disposal arrangements [65]. Full-scale simulators require significant set up and reoccurring costs (see Section 2.2), which may be avoided by software-based virtual simulation.

- *Repetition*: Real-world objects used for instruction naturally degrade or are used completely over time and must be replaced. Likewise, scenarios replicated virtually can be fine-tuned to be identical through each iteration, providing learners a baseline standard tool of use.

- *Room for Error*: Virtual simulation affords the learner to intentionally make and correct mistakes which would otherwise be unfeasible in the real world.

- *Effective Use of Resources*: Traditional simulation requires resources that virtual simulation does not. For example, busy operating room schedules could be prohibitive in letting trainees practice at their own pace of instruction. However, a software package can be used individually by students on their own time and schedule.

- *Customization*: Virtual simulation can accurately represent situations which are extremely rare and harder to replicate physically. For example, a specialized medical condition which is difficult to find a representative analogue for could be modeled virtually instead.

The decreasing cost and rising availability of immersive technologies has helped advance the adoption of virtual simulation in recent years. For example, hand motion tracking is accomplished by controllers such as the Razer Hydra, while the Leap Motion can precisely track the movement of individual fingers in 3D space. Haptic input devices such as the Novint Falcon provide a sense of touch and feedback to motion controls, while the Microsoft Kinect can be used to track the position of a user's entire body.

Virtual simulation has been used in a wide variety of fields. One such example is the Advanced Disaster Management Simulator (ADMS) developed by the Environmental Tectonics Corporation based out of Florida, United States. In the virtual simulation, emergency first responders can practice disaster response skills that improve critical thinking, decision making, and timely response to chemical, industrial, natural, and terrorist attacks [1]. ADMS provides a real-time physics-based virtual environment that authentically simulates all of the dynamic elements of a disaster scene including the locale, people, vehicles, infrastructure, and evolving threats [30]. Within healthcare, a series of virtual simulations named vSim for Nursing were used to provide opportunities to repetitively practice several nursing skills. Students who used vSim readily embraced the activity, with many reporting a deeper understanding of nursing concepts and an improvement in clinical reasoning and ability to prioritize post-use [32].

One immersive technology which has greatly benefited virtual simulation is virtual reality. Mihelj et al. defines virtual reality as "composed of an interactive computer simulation, which senses the user's state and operation and replaces or augments sensory feedback information to one or more senses in a way that the user gets a sense of being immersed in the simulation (virtual environment)" [67]. At a minimum functionality, VR systems typically utilize a head mounted display (HMD) as the primary way for a user to view and interact with a virtual world. A HMD is a display device worn on a user's head which uses optical lenses and one or two small displays to show computer-generated imagery (Figure 2.2). These headsets typically use various sensors embedded in the device (such as accelerometers or gyroscopes) to translate real-world movement and rotation into corresponding changes of the view of the virtual world.

Figure 2.2: The Oculus Rift HMD features adjustable head straps and built-in speakers for 3D audio [121].

The last few years has seen an explosive growth of interest into consumer-grade VR technologies, largely due to both increasingly smaller and more powerful computer hardware and the Oculus Rift. Promising to provide the next generation of VR HMD hardware, the Oculus Rift launched a Kickstarter crowd-funded project in 2012 supported by gaming and tech industry veterans such as Michael Abrash, John Carmack, Gabe Newell, Chris Roberts and Tim Sweeney [72]. By the end of the crowd funding campaign three months later, the project received a record breaking USD $2.4M in funding and is currently the 57th highest funded crowdfunding project in history [123]. After Oculus released an initial prototype to funders of the Kickstarter campaign to great fanfare, Facebook acquired Oculus for a staggering USD $2B in 2014. Believing the potential for the technology to connect people together in new and interesting ways, CEO of Facebook Mark Zuckerberg endorsed his vision of the future, “One day, we believe this kind of immersive, augmented reality will become a part of daily life for billions of people” [80].

Following the success of the Oculus Rift, various competitors, including various technology company giants, have entered the marketplace. Samsung designed and developed the Gear VR, an inexpensive headset which uses the owner’s mobile smartphone as the display and system processor. Sony began speaking of the ‘Codename Morpheus’ project, a VR headset which would integrate seamlessly into the Sony PlayStation 4. The project was later named PlayStation VR, and with a current PlayStation 4 install base of 40 million units (as of May 2016), it has been adopted as the mid-tier console-gamer entry point into VR [29]. The high-end consumer-grade

VR option is currently held by Taiwan-based HTC's Vive device, a package including a HMD, two hand controllers, and two base stations which track both the headset and controllers in a large 3D volume of real-world space. An overview of the different VR systems is provided in Figure 2.3.

	Samsung Gear VR	PlayStation VR	Oculus Rift	HTC Vive
Cost (excluding PC/console, USD)	$99	$399 (+$59.99 PlayStation Camera required)	$599	$799
Display	2560 x 1440 1280 x 1440 per eye Super AMOLED	1920 x 1080 960 x 1080 per eye OLED	2160 x 1200 1080 x 1200 per eye OLED	2560 x 1200 1080 x 1200 per eye OLED
Refresh Rate	60 Hz	120 Hz, 90 Hz	90 Hz	90 Hz
Included Motion Controllers	No	No. PlayStation Move controllers available ($99).	No. Oculus Touch to be released December 6th, 2016 for $199.	Yes
Sensors	Accelerator, gyrometer, geomagnetic, proximity	360 degree tracking, 9 LEDs	Accelerometer, gyroscope, magnetometer, 360-degree positional tracking	Accelerometer, gyroscope, laser position sensor, front-facing camera
Field of View	96 degrees	100 degrees	110 degrees	110 degrees
Audio	Phone speakers or headphone jack	Built-in 3D audio	Built-in 3D audio	Headphone jack
Tracking Area	Fixed position	10 x 10 ft	5 x 11 ft	15 x 15 ft
Minimum Hardware Requirements	Samsung Galaxy Note 5, Galaxy S6 series, or Galaxy S7 series	Sony PlayStation 4	NVIDIA GeForce GTX 970 or AMD Radeon R9 290 GPU, Intel Core i5-4590 CPU, 8GB RAM, HDMI 1.3, 2x USB 3.0, Windows 7 SP1	NVIDIA GeForce GTX 970 or AMD Radeon R9 290 GPU, Intel Core i5-4590 CPU, 4GB RAM, HDMI 1.3, USB 2.0
Weight	345 g	610 g	470 g	555 g
Release Date	November 27th, 2015	October 13th, 2016	March 28th, 2016	April 15th, 2016

Figure 2.3: Modern consumer-grade VR devices (as of October 2016) [53, 89, 114, 45].

One important difference between the various VR systems is the type of VR setup they are primarily designed for, and more specifically, either seated, standing, or room-scale experiences. These categories denote the ability of the system to track the user in different configurations.

Seated VR involves the user remaining seated in a chair a short distance away from a motion tracking sensor. The user generally spends most of their time facing towards the sensor, however some systems allow the user to turn around depending on whether the back of the headset can be tracked. The tracking volume of the sensor is the smallest of the three configurations, although the user still has some freedom to lean their body or slightly bend down while remaining in the chair. This small tracking volume may be troublesome for motion-tracked hand controllers though, as the user's range of movement with their hands is considerably wider than the range of movement of their head. This setup requires the least amount of physical space to use and the user is seated the closest to the tracking sensor. An example seated VR configuration is shown in Figure 2.4.

Figure 2.4: A typical seated VR setup. The tracking sensor is on the left beside the monitor and the user remains seated in a chair a short distance away [77].

Standing VR shares many similarities to the seated VR configuration, though the user remains standing in place instead of sitting. Due to the larger tracking volume required to see the full height of the user's body, the tracking sensor is placed further away from the user. Some systems may accomplish this larger tracking volume with multiple motion sensors, although it is not necessary. For example, the PlayStation VR uses a single sensor mounted above the user's TV, which is typically an adequate distance away from the user during game play. The user has an increased degree of freedom, as they may freely lean their body and reach down towards the floor. Motion-tracked hand controllers are more appropriate here due to this larger tracking volume. VR systems that allow standing VR also support seated VR. An example standing VR configuration is shown in Figure 2.5.

Figure 2.5: A typical standing VR setup. The tracking sensor is directly below the television and the user is standing a moderate distance away [112].

The last configuration, room-scale VR, allows the greatest user freedom by providing accurate tracking within a large enough space to walk around in. This increased freedom generally requires a secondary motion sensor and they are placed slightly above the user and face downwards. This allows the user to freely face any direction, bend down to the floor, and have consistently tracked hand controllers within a wide space. Room-scale VR requires the largest space to use, as a flat and clutter-free area must be made available to walk around in. Room-scale VR systems also allow standing and seated VR due to their requirements for use being exceeded. An example room-scale VR configuration is shown in Figure 2.6.

Figure 2.6: A typical room-scale VR setup. The tracking sensors are raised above the user and a large open space is available for free movement [70].

The skills acquired during virtual reality-based simulation training has been proven to transfer over to subsequent performance in operating rooms. Through the use of VR surgical simulation, for example, Seymour et al. compared the performance of surgery residents who were trained within the MIST VR simulator to those who were not [95]. During a following laparoscopic cholecystectomy procedure, those residents trained in the VR simulator out-performed those who were not: i) the operation was 29% faster overall, ii) they were nine times more likely to make progress, and iii) they were five times less likely to injure the gallbladder or burn nontarget tissue during the operation [95].

2.4 Anesthesia Simulation Training

As discussed briefly in Section 2.2, the success of Gaba's Comprehensive Anesthesia Simulation Environment introduced the healthcare specialization of anesthesia to simulation-based training [36]. In the coming years, many imitators would offer different types of simulation to anesthetists. Gaba classifies anesthesia simulators into three categories: i) realistic simulators or hands-on simulators, ii) computer screen-only simulators or micro-simulators, and iii) virtual reality simulators [35].

Full-scale hands-on simulators recreate the anesthesia work environment in which the mock patient and equipment look, feel, and behave as they do in real life [17].

Gaba's CASE was one of the first examples of this, although future iterations improved upon the idea [36]. For example, the Eagle Patient Simulator contained complete models of cardiovascular, pulmonary, fluid, acid-base and thermal physiology within a full-body computer-controller mannequin [17]. Set up within an operating theatre with nurses and surgeons playing specific roles within a simulation session, the Eagle was used to train Anesthesia Crisis Resource Management (ACRM) skills.

Computer screen-only simulators are less expensive, more widely used, more flexible overall, and can more easily be adapted to a specific user's needs [17]. These simulators replicate the entire anesthesia work environment virtually within the computer system. Screen-based simulators relating to anesthesia training include the Anesoft Anaesthesia simulator, BODY, BreathSim, and Wang's Simulator [24, 31].

Virtual reality-based simulators are less common particularly in the domain of anesthesia. Many VR simulators focus on teaching specific psychomotor tasks such as needle or catheter insertion and in the use of ultrasound imaging, though some of these are applicable to anesthesia [24, 17]. One example developed by Laerdal is Virtual I.V., a system which uses a specialized force-feedback needle and software to train students how to start an intravenous infusion or draw blood [17, 10].

Anesthesia simulation-based training has long-since proven itself to be an effective teaching method. These simulators have been shown to improve clinician performance from both a medical/technical skills and behavioral perspective from as early as 1998 [37]. For example, Schwid et al. showed that the use of a screen-based anesthesia management simulator improved trainee performance when transitioning over to mannequin-based simulation [93].

2.5 Serious Games

Drawing from the need for innovative, non-traditional learner-centric approaches to education, the industry has taken advantage of the inherent interactivity, motivation, and engagement of video games towards learning applications. Termed 'serious games', these are specific types of games whose primary purpose goes beyond pure entertainment by teaching knowledge or training skills [33]. The use of serious games falls under the category of 'game-based learning', which describes "the application of games for teaching competences and skills in a selected area of knowledge or the informal learning while playing a game" [33, 39, 78].

Although traditional and virtual simulation can be learner-centric, serious games take this concept a step further by using video game constructs to provide a high level of interactivity whereby the learner is in control of the progression of the serious game and therefore the pace of instruction. As such, games are specifically designed to promote long-term user engagement and motivation. With respect to video games and simulation, Becker and Parker describe their relationship with serious games as such: serious games (referred to as simulation games by Becker and Parker) are a subset of games, which is a subset of simulation [5]. A visual representation of this relationship is provided in Figure 2.7.

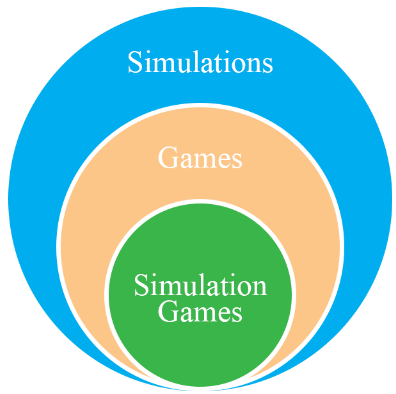


Figure 2.7: According to Becker and Parker, all serious games (referred to as simulation games by Becker and Parker) are games and all games are simulations [5].

While designing or evaluating the usefulness of serious games, it is important to consider a common set of variables that might contribute to learning, realism and engagement within serious games. With these common variables, designers could make sure to include them in the development of new serious games and could serve as axes upon which the effectiveness of such games could be evaluated. Various authors have attempted to address this issue. For instance, Thiagarajin and Stolovich proposed five characteristics which should be included in serious games [113]:

- *Conflict*: Can be described as challenge.
- *Constraints on a player's behaviors*: Rules.
- *Closure*: The game must come to an end.
- *Contrivance*: All games are contrived situations.
- *Correspondence*: Designed to respond to some selected aspects of reality.

Coming specifically from a serious games evaluation perspective, Tashiro and Dunlap propose ten meaningful game attributes which serious games should possess in order to be effective and engaging [110]:

- Clear learning goals.
- Broad experiences and practice opportunities that continue to challenge the learner and reinforce expertise.
- Continuous monitoring of progress and use of this information to diagnose performance and adjust instruction to a learner's level of mastery.
- Encouragement of inquiry and questions, and response with answers that are appropriate to learner and context.
- Contextual bridging, that is, closing the gap between what it is to be learned and its usefulness to the learner.
- Engagement leading to an increased time on task within a learning game environment.
- Motivation and strong goal orientation.
- Scaffolding in the form of cues, prompts, hints, and partial solutions to keep learners progressing through the activities in a learning game.
- Personalization that allows tailoring of learning to the individual learner.
- Infinite patience inherent in a game environment that literally does not tire of repetitive actions and so provides learners with innumerable opportunities to try an activity over and over.

Though various models and recommendations for the design and evaluation of serious games exist, common attributes, among others, seem to be: i) objectives defined by specific learning goals, ii) an attempt to create user engagement through 'fun', and iii) taking a learner-centric approach to education by allowing the player to progress at their own pace.

Serious games have been developed and employed in a wide variety of fields, such as: language learning [49], chronic pain rehabilitation [91], social change with respect to humanitarian aid [75], and the treatment of specific phobias using mobile devices [9]. One such example is a serious game designed to strengthen computer programming skills by Muratet et al. [69]. Citing a decreasing global interest in science from college and university-level students, Muratet et al. adapt the open source Spring game engine to develop a real-time strategy game. In the game, students control game entities by programming their own artificial intelligence and combat their friends in a multiplayer game mode [69].

With respect to medical education, a wide variety of serious games have been developed to address a number of healthcare skills and professions: total knee replacement surgery [87], oncology patient management [34], and dental implant surgery [94] to name a few. Existing reviews of serious games for medical education can be found by Wattanasoontorn et al. [122] and Kato [54].

2.6 Previous Work

Fortunately, my work with serious games, simulations, and VR started before I began my Master's studies and continued throughout. This body of work formed a foundation of experience and informed the main thesis work with the ACLS and HTC Vive projects that form the basis of this thesis. In this section I outline this previous work that involved the development of several serious games for health professions education and physical rehabilitation and detail how they individually contributed to the direction that this thesis follows.

2.6.1 ZDOC

My experience with serious games began at the end of my second undergraduate year when I started collaborating with Dr. Aaron Knox, a plastic surgeon from the University of British Columbia. Together we developed ZDOC, a prototype serious game for training plastic surgery residents the steps comprising the Z-plasty surgical procedure [96].

A Z-plasty is a fundamental plastic surgery technique used to improve the functional and cosmetic appearance of scars by transposing constricted or unsightly soft tissue into a better functional position or into alignment with a natural skin fold or line of least skin tension [88]. In the basic Z-plasty procedure two triangular flaps of equal length and dimension are oriented at 60 degrees to a central limb containing the scar or defect to create a "Z-like" incision. The two triangular flaps are then transposed, changing the orientation of the central limb and augmenting its length [88]. Although the actual procedure may be simple, the pre-operative planning is crucial to the intended end result and application of these techniques involves complex reasoning and 3-dimensional mental reconstruction [47]. Although most surgeons possess the dexterity required to perform the operation, many find it difficult to understand the geometry (flap orientation, size, and angles) required to best treat a defect in a certain area. Furthermore, residents are typically first introduced to the procedure using "traditional" education methods such as textbook readings which are not ideally suited for teaching or practicing visual-spatial relationships inherent in the method [26].

Due to the rising availability of smartphone and tablet devices at the time, ZDOC was targeted as a serious game utilizing a touch interface which surgery residents could play with on their own, readily available hardware. In the game, the trainee explores a 3D patient's head and targets specific areas which need the Z-plasty procedure performed (Figure 2.8). An incision line is drawn on top of the scar tissue, followed by two minigames to practice skiving (holding the scalpel perpendicular to the incision plane) and undermining (cutting underneath the skin to create a flap) skills (Figure 2.9). Finally, the trainee transposes the 3D flaps and sutures them together (Figure 2.10).

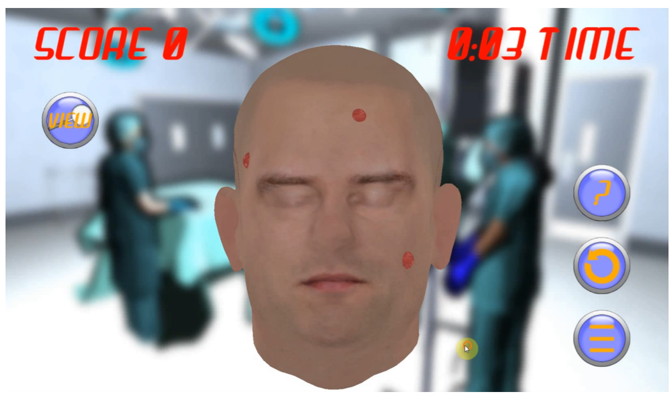


Figure 2.8: ZDOC: The patient's head.

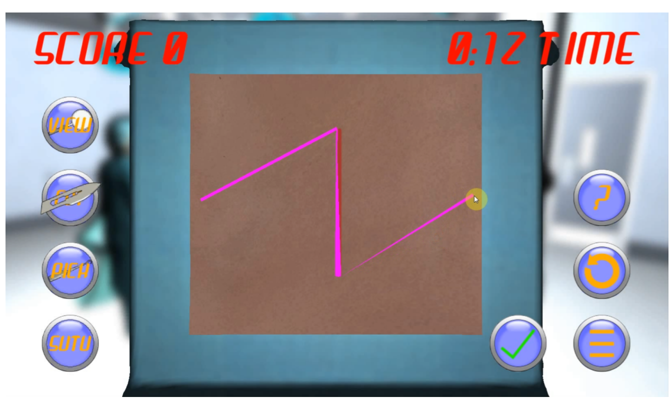


Figure 2.9: ZDOC: Drawing the incision line.

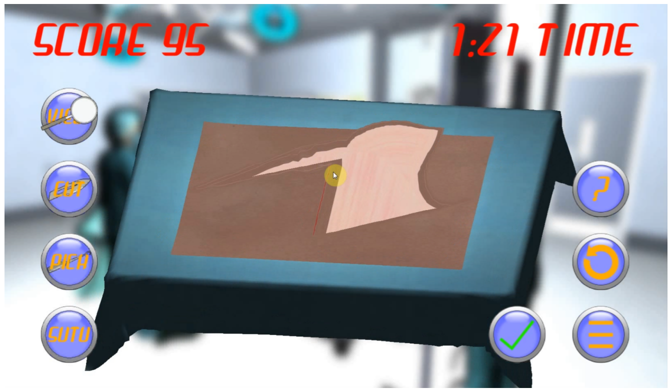


Figure 2.10: ZDOC: Transposing the flaps.

From this project, I began to see the enthusiasm which medical experts direct towards non-traditional teaching methods such as serious games for learning. This was my first instance of collaborating with an outside client from the medical world, and his surgical knowledge and experience helped drive the project to fit a real need for surgical residents. This need for serious games in the medical industry exists, yet I took away a feeling that developing single-use serious games designed to address one particular problem might not be the best showcase for their potential. This idea would lead to my future work developing tools for medical educators to utilize instead of serious games themselves.

2.6.2 Rapid Recovery

Aside from collaborating with medical experts, I have also had the chance to work with industry entrepreneurs interested in the power of serious games as a complementary tool to a physical product. One such product is the Spincore Helium 6 Baton, a stand-alone fitness and rehabilitation device that provides individuals the opportunity to obtain a full upper body muscle and cardio workout [105]. Building upon a previous version of the serious game, I was part of a small team which developed and alpha tested Rapid Recovery, a serious game using the Microsoft Kinect motion sensing device [92, 66, 98].

Although exercise has been associated with reducing all-cause mortality, only 25% of adults regularly participate in recommended levels of physical activity [56, 73, 8, 14]. As a subset of video games that are also a form of exercise, exergaming ("exercise" and "gaming") aims to leverage the inherent benefits of video games such as a high levels of engagement and immersion in order to promote physical activity [100]. By focusing on the specific problem of shoulder rehabilitation and physical fitness after an injury, Rapid Recovery was developed as a novel and engaging exergame designed to be used with the Helium 6 Baton.

Utilizing the Microsoft Kinect, Rapid Recovery assists players in following proper rowing techniques while using the Helium 6 Baton. The Kinect motion sensing camera views the player's physical body and moves an avatar's virtual body to match. By using the Kinect, the game can evaluate the player's motions and offer constructive feedback. A tutorial guides the player in proper body posture and arm position against a reference model (Figure 2.11). The player then rows through a selection of courses while navigating checkpoints, exercising with the Helium 6 Baton (Figure 2.12).

Figure 2.11: Rapid Recovery: Tutorial. Reference model on the left, player on the right.

Figure 2.12: Rapid Recovery: Game play. Navigating towards a checkpoint.

Rapid Recovery was alpha tested with 12 participants, focusing on the participants' subjective satisfaction with the user interface as well as several open-ended questions. This project provided a number of takeaways which I continued to consider throughout future work. Most notably, designing a serious game to model a real-world situation and environment raises the visual and audio fidelity requirements, as trainees seek to feel comfortable and related to the game. Also, representing physical tasks which trainees may not have performed previously in a virtual setting requires sufficient feedback provided by the system in order to reassure the trainees that they are performing the actions correctly. This was my first project working with an industry partner, showcasing the potential for serious games to have a wider reach than limited to the medical field. The use of a separate computing device such as the Kinect offered unique solutions to open problems involving physical movement, and I continued exploring various computer peripherals throughout future work. Finally, I gained an understanding that user testing serious games is critical to their development, as is it a method of validity checking that the design of the serious game is leading to the desired outcomes. In the case of Rapid Recovery, the feedback received during user testing was used to improve the game to a later stage. These lessons were brought forward to produce higher fidelity serious games and tools which subsequently underwent user testing of their own.

2.6.3 Cultural Game

In addition to using the benefits of serious games to help both industry partners and medical professionals, I turned to improve the quality of care patients experience in culturally diverse societies. To this aim, I developed the Cultural Game, a scenario-based, interactive serious game for healthcare-based cultural competence education and training [97].

Despite the importance of cultural competence in healthcare, research indicates that medical education isn't keeping pace with changing composition of patient populations in culturally diverse societies such as Canada and the United States [3]. Healthcare providers don't automatically possess the attitudes or skills required to be effective within a culturally diverse healthcare setting. However, the quality of patient care is compromised when healthcare providers don't respond appropriately to patient cultural factors [52]. Kripalani et al. proposed a list of elements to improve cultural competence training in medical education including the following that lend themselves to the application of interactive media such as serious games (i.e., the use of video games for education and training) for this purpose: i) use of interactive educational methods, ii) provide direct instructor observation/feedback, and iii) promote cultural diversity at all levels of medical school, amongst others [55].

The Cultural Game was my first attempt at providing medical educators both a serious game for training and education as well as a tool which they could use to develop their own scenarios. The game portion involves the trainee taking on the role of a doctor, navigating a 3D environment resembling a hospital patient wing. The trainee interacts and has conversations with various avatars within the environment, such as other doctors and nurses, patients, or the patients' families (Figure 2.13). By choosing one of the provided dialogue options, the game provides useful feedback relating to how the trainee is interacting with different members of the hospital environment; whether they are respecting patient cultural customs and whether they are being insensitive to particular issues which some diverse workplace colleagues might raise.

Figure 2.13: Cultural Game: The trainee chooses a dialogue option while conversing with a nurse.

The novel portion, however, was the attempt to provide the tools necessary for medical educators to craft both their own hospital environments and dialogue trees for use within the game. The scene editor allows the educator to intuitively place walls, doorways, and objects within rooms, creating a hospital environment that matches their own real world physical space (Figure 2.14). The user interface and interaction design were modeled after the Sims franchise of highly successful simulation video games in which the player creates houses and living spaces from scratch [28]. The dialogue tree editor allows the educator to craft a back-and-forth conversation between characters within the created environment, allowing for branching trainee choice and defining the system's reaction to these choices. The visual analogue of sticky notes on a corkboard was used to help provide an easily understandable user interface (Figure 2.15).

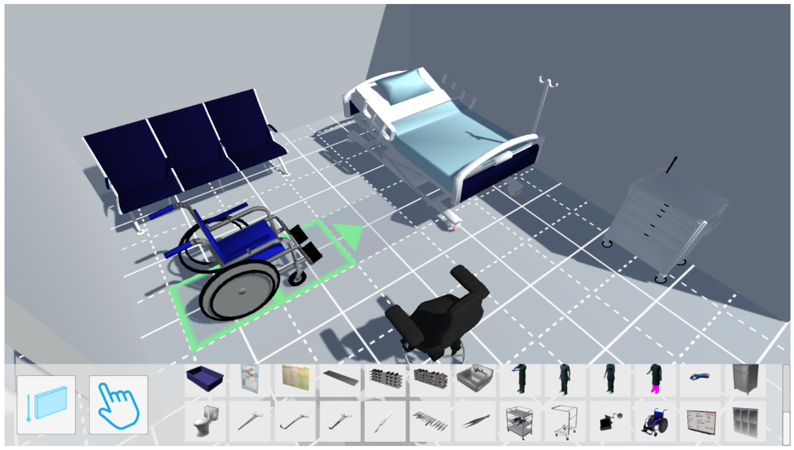


Figure 2.14: Cultural Game: Placing objects within the scene editor.

Figure 2.15: Cultural Game: Branching dialogue tree between doctors within the virtual environment.

Throughout this project, I learned a number of lessons which would inform the later thesis work. Namely, the power of providing medical educators with the tools they need to author and customize their own serious game scenarios, instead of providing them with a one-stop purpose-built application. Although developing a single serious game to address one open problem leads to a higher degree of specificity and overall quality of the final game, this type of development suffers from a short reach across multiple projects and open problems yet to be faced. With the Cultural Game, although the focus was placed on educating healthcare professionals on culturally sensitive issues they might face in their daily working lives, the power of the scene and dialogue editor allows the game to address cultural issues that I as the developer might not have the budget of knowledge base to develop. By providing medical educators usable, efficient, and effective tools to create their own serious gaming scenarios, a larger number of open problems can be addressed than with single-purpose built serious games and simulations.

2.6.4 Intangible Table + Tablet

After a thorough exploration of serious games and their capabilities with traditional desktop computers, I began to further investigate the use of different hardware and peripherals to meet unique needs not previously addressable. For example, many surgical skills require fine hand precision during operation, and immersive technologies such as motion-tracked hand controllers could be incorporated into virtual simulations. Working on a cooperative research project with the University of Toronto (Toronto, Canada) and Shizuoka University (Hamamatsu, Japan), we developed the Intangible Table and Tablet project aimed at supporting learner-centric ophthalmic anatomy education [18].

One key area of importance within medical education is the subject of human anatomy training. As human anatomy training helps prepare medical undergraduate trainees for their separate clinical specialties, it is a vital part of ensuring safe and efficient medical practice [79, 4]. This training often involves the instructor and students gathered around a cadaver table with a cadaver (or dummy cadaver/manikin) placed on top of it. This follows a "one size fits all" approach to education, whereby the instruction is not tailored to the diverse individual experiences, knowledge, and skills across the group of learners. In contrast, a learner-centric approach to education places the importance on the learner over the instructor to the instructional activity. By removing the instructor as the primary conduit between the learner and the learning experience, the learner can approach the content according to their own style and with their own background knowledge in mind [57]. To investigate the benefits of this approach to education, we developed this project to enable ophthalmic anatomy education along a learner-centric approach using various devices.

The system employs the use of augmented reality, a tabletop display, and mobile devices (tablets and smartphones) to provide a learner-centric approach to ophthalmic anatomy education. The tabletop display provides a touch-sensitive interaction surface with a global view of an anatomical eye model (Figure 2.16). This view can be manipulated by all trainees and the instructor, moving, rotating, and altering (hiding, selecting) layers of the model (Figure 2.17).

Figure 2.16: Intangible Table and Tablet: Touch-sensitive tabletop display.

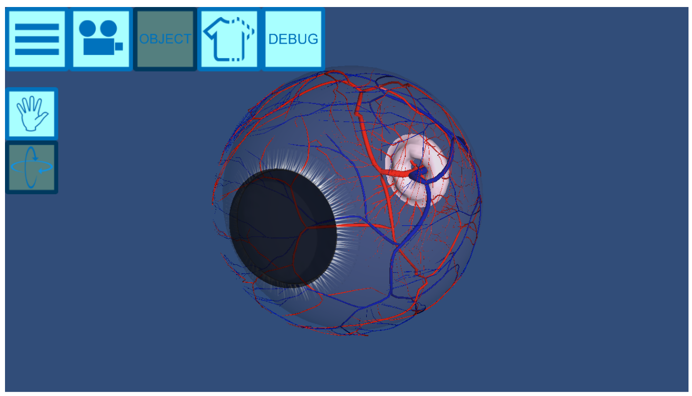


Figure 2.17: Intangible Table and Tablet: Main tabletop view of an anatomical eye model.

Each of the trainees have a personalized augmented reality view of the model in 3D space above the tabletop display using mobile devices (Figure 2.18). This view of the model is synchronized to the tabletop display, enabling the instructor to guide students along through a lesson by manipulating the tabletop. Finally, the mobile displays can enter an inspection mode which simulates an ophthalmoscope, enabling students to explore the inside of the eye and practice isolating key components of the inside anatomy (Figure 2.19).

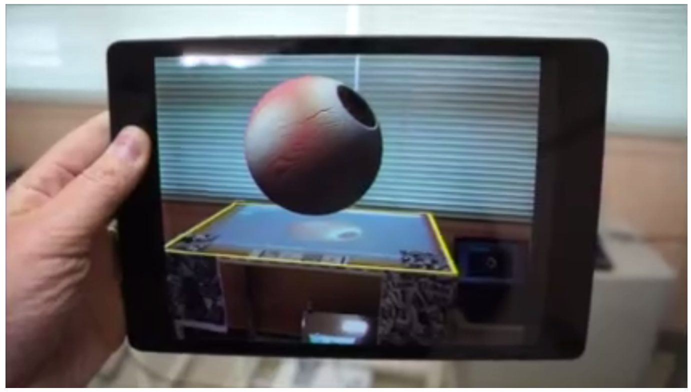


Figure 2.18: Intangible Table and Tablet: Augmented reality enabled tablet view.

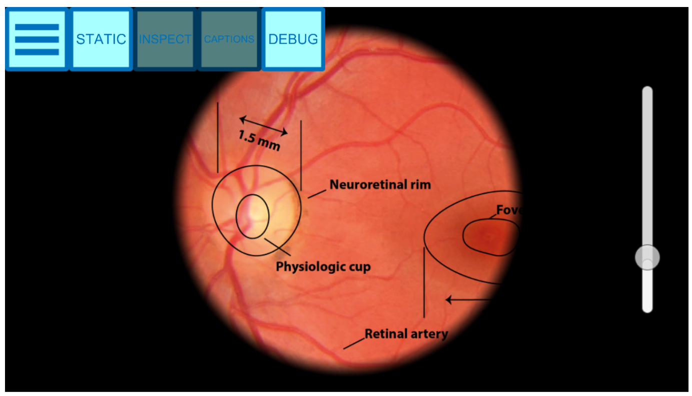


Figure 2.19: Intangible Table and Tablet: Ophthalmoscope view with captions enabled.

As a result of this project, my interests were furthered in using the newest emerging technology in conjunction with serious games applications. The widespread availability of tablet and smartphone devices allowed for a novel learner-centric approach to ophthalmic anatomy education which was not previously possible. This interest in using the newest technology for novel applications would guide the thesis work using the HTC Vive VR headset.

2.7 Summary

Within this chapter I have discussed the literature on the topics of traditional and virtual simulation, virtual reality, anesthesia simulation training, and serious games, concluding with an overview of my own previous work in these areas.

Simulation, the act of immersing a learner within a recreated scenario, has proven to be an effective educational technique that allows interactive and immersive activity during practice. With historical roots in flight pilot training, simulation has expanded greatly and been adopted especially in the healthcare industry. Although there are benefits to simulation, such as low risk to others or the acceptance of learning from error, prohibitive cost raises a high barrier of entry.

This prohibitive cost has been partially addressed through virtual simulation, or the use of simulation through such immersive technologies as software, mobile phones, or haptic input devices. In particular, virtual simulation offers the ability of consistent repetition and the effective use of resources not readily found through traditional simulation. One immersive technology which has seen a massive resurgence of popularity is virtual reality, an interconnected system of devices which measure and respond to a user's senses to provide immersive feedback. This system can be employed through a seated, standing, or room-scale setup, each of which has benefits and drawbacks in comparison to the others.

In particular, the healthcare field of anesthesia has historically been an early adopter of simulation. Throughout the years it has been useful to classify anesthesia simulators into three distinct categories: i) realistic or hands-on simulators, ii) computer screen-only or micro-simulators, and iii) virtual reality simulators.

A subset of simulations purposefully include traditional video game elements to promote fun, and are denoted as serious games. These serious games leverage the inherent interactivity, motivation, and engagement found within video games to promote learning outcomes. Common attributes within effective serious games include: i) objectives defined by specific learning goals, ii) an attempt to create trainee engagement through fun, and iii) taking a learner-centric approach to education by allowing the trainee to progress at their own pace.

Finally, my previous work developed prior to Master's studies include various serious games for surgical skills, physical rehabilitation, cultural competence, and ophthalmic anatomy education. These projects grew my interest in learner-centric methodologies of education such as simulations and serious games, and has continued to guide my work with immersive technologies such as VR.

Chapter 3

ACLS Serious Game

3.1 Overview

The first of two serious games developed in this body of work was in collaboration with Dr. Fahad Alam and Dr. Kenneth Lee from the Department of Anesthesia, University of Toronto, and the Sunnybrook Health Sciences Centre in Toronto, Canada. Dr. Alam and Dr. Lee were interested in using the inherent engagement in serious games to promote a learner-centric approach to Anesthesia Crisis Resource Management skills.

Similar to airline pilots, medical anesthesiologists must exert specific cognitive, (non-technical) skills to successfully manage the available resources during both normal and crisis situations. Summarized as the articulation of principles of individual and crew behaviour in ordinary and crisis situations that focuses on skills of dynamic decision-making, interpersonal behaviour, and team management, the Crew Resource Management (CRM) paradigm has been adapted to anesthesia training and known as the Anesthesia Crisis Resource Management (ACRM) paradigm [43]. A subset of these skills dealing with crisis situations includes the Advanced Cardiovascular Life Support (ACLS) intervention, that incorporates a set of clinical interventions for the urgent treatment of cardiac arrest, stroke, and other life-threatening medical emergencies, in addition to the knowledge and skills to deploy those interventions. These skills are typically taught through a teacher-centered approach that requires a staff anesthesiologist in the learning environment.

Dr. Alam and Dr. Lee were also keen on leveraging the possibilities of recently available consumer-level VR technologies within the ACLS serious game. To outline a development path going forward, an initial version of the game was developed for desktop computers which was subsequently usability tested to highlight and correct any issues before further development. The results of this initial desktop version of the serious game, and the usability testing, are outlined in this chapter. Concerned with the question of whether or not seated- or room-scale VR should be employed after this initial usability testing, a separate serious game was designed and developed to investigate an answer. The results of this second serious game development and testing are outlined in Chapter 4.

3.2 Game Description

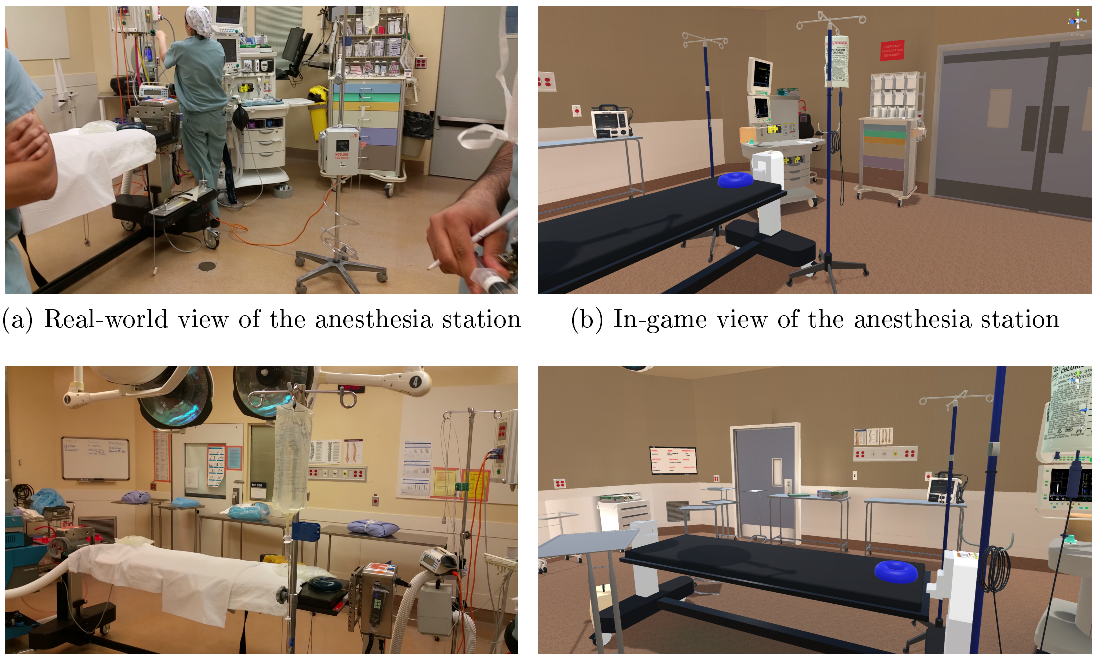
In the ACLS game, the trainee assumes the role of an anesthesiology resident beginning their shift during an ongoing laparoscopic surgery that started 30 minutes prior. Complications arise with the patient during the surgery and the trainee must properly react to these issues by manipulating the anesthesia machine, giving instructions to the surgeons, and administering different intravenous line fluids. The scenario was designed and validated by Dr. Alam and Dr. Lee as an accurate representation of a similar real-world scenario with the necessary steps needed to be taken to ensure a positive patient outcome. The full scenario description can be found in Appendix 1.

The game is set in a 3D virtual operating room environment utilizing a first-person view. Mimicking typical first-person shooter video game controls, the trainee moves their virtual avatar within the environment with keyboard and mouse controls, clicking the mouse button to interact with different in-game elements. A list of objectives in the on-screen User interface (UI) guides the trainee into completing a number of objectives as the scenario progresses. An in-game view, as well as a layout of the virtual operating room, are detailed in Figure 3.1.

(a) In-game first-person view (b) Operating room top-down layout

Figure 3.1: Virtual operating room.

The game was developed using the Unity 3D game engine while Autodesk Maya was used to develop the 3D models. Adobe Photoshop was used to create textures for both 2D elements and 3D models. Great care was taken to accurately replicate the physical and audio characteristics of a real-world operating room in the Sunnybrook Health Sciences Centre, in Toronto, Canada. Video, picture, and audio reference were taken on-site and later used in the development of 3D models and the layout and size of the room. An example of this replication can be seen in Figure 3.2.



(a) Real-world view of the anesthesia station (b) In-game view of the anesthesia station

(c) Real-world view of the surgeon area (d) In-game view of the surgeon area

Figure 3.2: Real-world vs. in-game comparisons.

Throughout the scenario the trainee completes 16 objectives which involve moving within the room, looking at different elements (such as the anesthesia monitor), and interacting with different objects (such as the patient's anesthetic record, or the anesthesia monitor's buttons). Objects within the environment which the trainee is intended to interact with pulse a glowing green color to indicate their importance. To better understand the significance of the usability results, each objective (OB) in the scenario is briefly outlined below.

- OB1) InStandTarget: The trainee moves from their starting position to the anesthesia station and faces the patient bed.
- OB2) GrabAnestheticRecord: The trainee faces the patient record and clicks to view it.

- OB3) CheckedMonitors: The trainee faces each of the two anesthesia monitors.
- OB4) GrabDrugVial: The trainee faces the drug vial and clicks to view it.
- OB5) CheckSuctionContainer: The trainee faces the suction container to view it.
- OB6) CheckedElements1: The trainee faces each of the following elements on the anesthesia monitors: blood pressure, heart rate, EtCO2.
- OB7) InformSurgeons: The trainee faces any one of the surgeons and clicks to inform them.
- OB8) CycledNIBP: The trainee faces the buttons on the anesthesia monitors and clicks to activate them. Cycling the blood pressure cuff takes two button presses.
- OB9) ChangedO2Sev: The trainee faces the buttons on the anesthesia monitors and clicks to activate them. Changing the O2 and Sev output take four button presses.
- OB10) OpenIVLine: The trainee faces the intravenous line stand and clicks to open it.
- OB11) CheckedElements2: The trainee faces each of the following elements on the anesthesia monitors: blood pressure, heart rate, SPO2, EtCO2.
- OB12) AskNurseBlood: The trainee faces the circulating nurse and clicks to interact with her.
- OB13) CheckedElements3: The trainee faces each of the following elements on the anesthesia monitors: blood pressure, heart rate, SPO2, EtCO2.
- OB14) PalpatePulse: The trainee faces the patient on the bed and clicks to palpate for a pulse.
- OB15) DirectSurgeonChestCompressions: The trainee faces any one of the surgeons and clicks to direct them.
- OB16) AskNurseCrashCart: The trainee faces the circulating nurse and clicks to interact with her.

The game features continuous background ambient sound in the form of soft machine beeping noises and surgeon chatter as would be typically found in an operating room. Various sound effects which are triggered by the completion of different objectives include an increased suction noise from the anesthesia machine's suction container as well as the warning noises played by the anesthesia machine during a rapid change in patient vital signs. The virtual surgeons do not animate, as they remain fixed in a pose and do not move within the environment.

3.3 Hypotheses

The usability study was conducted in order to answer three main questions: i) are there usability issues within the game interface, controls, or game play, ii) is the game engaging, and iii) does the game feel realistic and intuitive. Hypotheses for the results of the testing are as follows:

- Minor usability issues exist within the game's interface or game play.
- The game is engaging for the participant to play.
- The game feels realistic, especially regarding the visuals and audio.

3.4 Participants

A total of 40 participants participated in the usability study, eight of which were female. Participants were staff and students at UOIT aged 18-30, with the majority being 18-20 (35%) or 21-23 (32.5%). Participants were particularly recruited from both the Game Development and Entrepreneurship (GDE) undergraduate program and numerous Health Sciences undergraduate programs in an effort to gain both usability experts as well as potential end-user perspectives. The GDE students are formally trained in methods of usability and user experience with respect to software and video games, and the health sciences students represent the end users of these types of serious games for healthcare. 15 participants (37.5%) were from the GDE program and six (15%) were from various Health Sciences programs encompassing Kinesiology, Human Health Sciences and Medical Laboratory Science. Participants who were not from either of these two programs were staff or students in different disciplines. Participants enrolled in the study voluntarily and were not compensated for their participation. The experiment was approved by the Research Ethics Board of UOIT with reference number 15-143.

3.5 Experimental Procedure

The experiment took place in the Game Science Lab at UOIT and only one participant participated in the experiment at a time. The Game Science Lab was laid out with a small desk and office chair facing a large television. The computer keyboard and mouse was placed on the desk and a pair of speakers were used under the TV to provide sound output. Participation in the study involved only a single session and did not require performing any additional activities outside of the duration of their session. No additional material was required, and an experimenter was in the room with them at all times behind a cubicle wall separating the play area from the data collection area.

Participants were first welcomed into the lab and asked to sit at the desk. After explaining the experiment, methods of data collection and participant rights, consent was obtained. Participants were then asked to complete a demographics questionnaire brought up on the monitor (see Appendix 2). After completing the questionnaire, the experimenter explained the purpose of the game and the controls, brought the game up on the monitor, and asked participants to begin whenever they were ready. The experimenter left the play area and only returned once the participant finished the game play session. The game play session lasted a maximum of 10 minutes. When the game play session was completed, participants were asked to complete a feedback questionnaire displayed on the monitor (see Appendix 3). Finally, participants were thanked for their time and asked whether they had any questions.

3.6 Methods

The feedback questionnaire was comprised of several different questionnaires widely used to assess the usability of user interfaces and game engagement: the Questionnaire for User Interface Satisfaction (QUIS), the System Usability Scale (SUS), and the Game Engagement Questionnaire (GEQ). The feedback questionnaire also contained open-ended questions specific to the ACLS serious game to obtain the participant's subjective opinions on the game's perceived realism and intuitiveness.

The Questionnaire for User Interface Satisfaction (QUIS) is designed to measure the user's subjective rating with specific aspects of the human-computer interface [16]. Answers to each of these questions are based on a 10-point Likert scale and are divided into five categories: i) overall reactions to the system, ii) screen, iii) terminology and system information, iv) learning, and v) system capabilities. Higher scores to each question indicate a higher degree of user satisfaction.

The System Usability Scale (SUS) is a reliable usability scale that can be used for global assessments of systems usability [12]. Ten questions cover a variety of aspects of system usability, such as the need for support, training, and complexity, and are based on a 5-point Likert scale. It yields a single score representing the composite measure of the overall usability of the system being studied and the score has a range of 0 to 100. Higher scores indicate a higher degree of overall system usability.

The Game Engagement Questionnaire (GEQ) contains 19 questions and provides a psychometrically strong measure of levels of engagement specifically elicited while playing video games [11]. Each question can be responded to with one of three options: i) No, ii) Maybe, and iii) Yes and each option is assigned a numerical value: i) No = -1, ii) Maybe = 0, and iii) Yes = 1. Questions are grouped into the four categories of i) Immersion, ii) Presence, iii) Flow, and iv) Absorption, with each subsequent category representing an increased difficulty for the responder to answer favorably. A definition for engagement and each category is provided below.

Engagement

When developing the GEQ, Brockmyer et al. define engagement loosely as "a generic indicator of game involvement" [11]. Similarly, Maslach et al. state that engagement is characterized by energy, involvement, and efficacy [60]. These characteristics are noted as being the opposite of burnout, a state of mental weariness [90].

Immersion

The definition of immersion varies into one of two schools of thought. Many authors use the terms 'immersion' and 'presence' interchangeably to refer to a technological system's ability to giving a user an enhanced sense of "being there" [74]. The second school of thought seeks to define a harder separation between immersion and presence, typically when dealing with virtual reality technologies. Slater et al. pioneered this approach, reserving 'immersion' to "stand simply for what the technology delivers from an objective point of view" [102, 101, 103]. McMahan et al. follow suit, describing immersion as "the objective level of fidelity of the sensory stimuli produced by a technological system" [64]. It is an objective measure which is a combination of many technological components, such as resolution, field of view (FOV), and stereoscopy [64]. The GEQ takes the first approach, referring to immersion as "the experience of becoming engaged in the game-playing experience while retaining some awareness of one's surroundings" [11].

Presence

Regardless of whether authors decide to separate immersion and presence or use the terms interchangeably, presence has been defined as “the degree to which participants feel that they are somewhere other than where they physically are when they experience the effects of a computer-generated simulation” [13].

Flow

Flow is a term originally associated with Mihaly and Isabella Csikszentmihalyi, defined as “a psychological state in which the person feels simultaneously cognitively efficient, motivated, and happy” [68]. When the perceived challenges of a system are met adequately by the user’s ability, a feeling of enjoyment and increased learning outcomes result [23, 11].

Absorption

The most difficult for a user to experience, absorption is defined as “a ‘total’ attention, involving a full commitment of available perceptual, motoric, imaginative and ideational resources to a unified representation of the attentional object” [46]. This state of consciousness results in a heightened sense of the attentional object with an imperviousness to distracting events [111].

The QUIS, GEQ, and SUS, have been discussed, verified, and accepted as valid measures for usability testing and game engagement evaluation of a variety of technology-based applications including games, serious games, and simulations, among others [6, 61, 71]. They have also been used alongside electroencephalogram and physiological signal analysis for assessing flow in video games [7], and to investigate the relationship between Metacritic scores and player experience [48].

Game play metric data was collected by the software in the form of recorded timestamps for the completion times of each objective.

3.7 Results

The following section details the results for the feedback questionnaire and its subsequent sections, the collected game metrics, and ends with a discussion regarding the open-ended questions.

3.7.1 Questionnaire for User Interface Satisfaction (QUIS)

Each category of QUIS (i.e.(i) overall reactions to the system, (ii) screen, (iii) terminology and system information, (iv) learning, and (v) system capabilities) has been separated and the mean results for each are detailed in Figures 3.3-3.7.

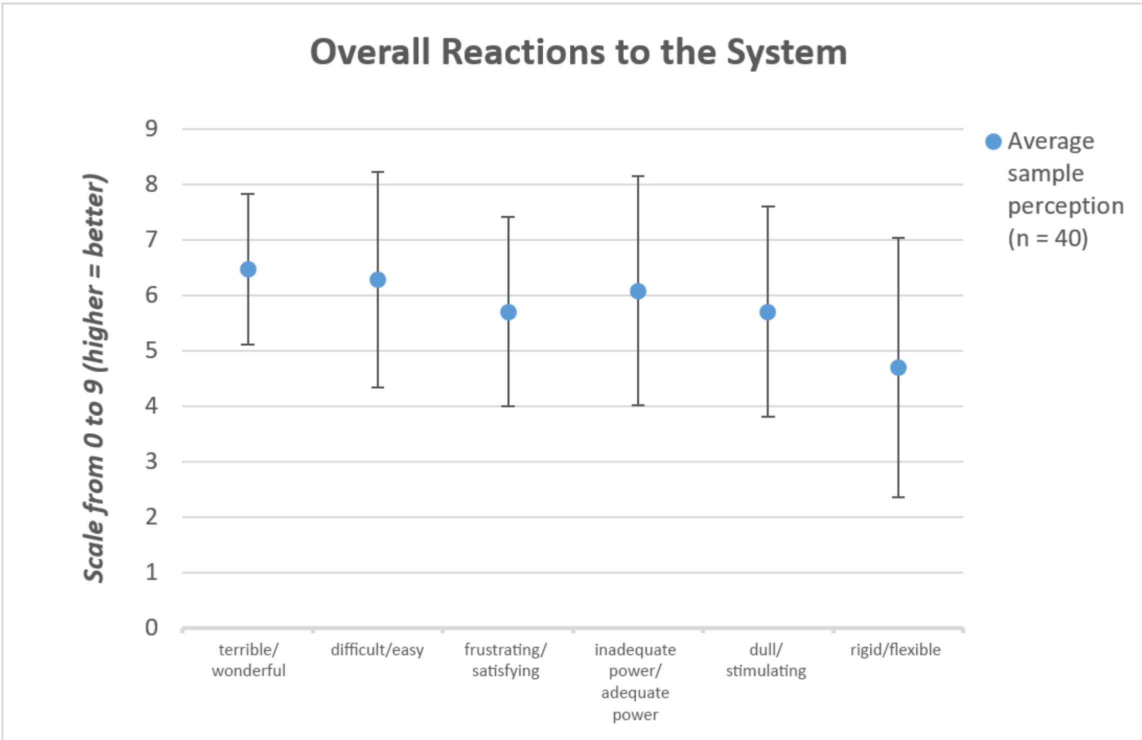


Figure 3.3: QUIS mean results: Overall Reactions to the System showing standard deviation.

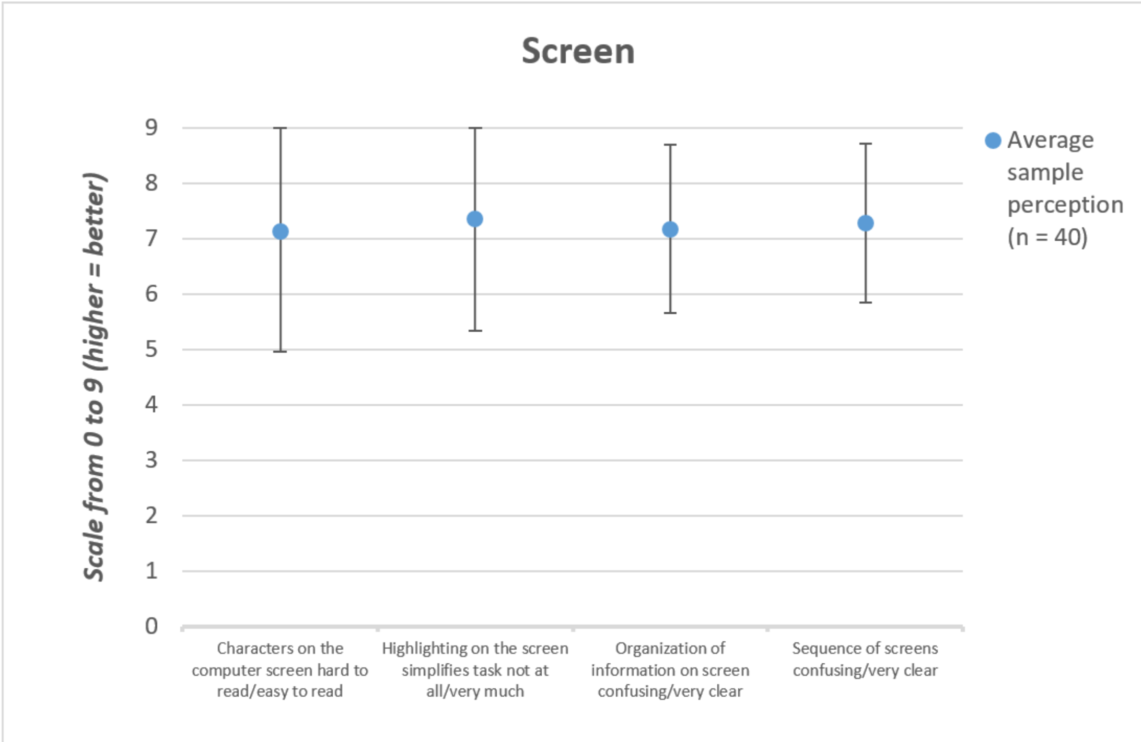


Figure 3.4: QUIS mean results: Screen showing standard deviation.

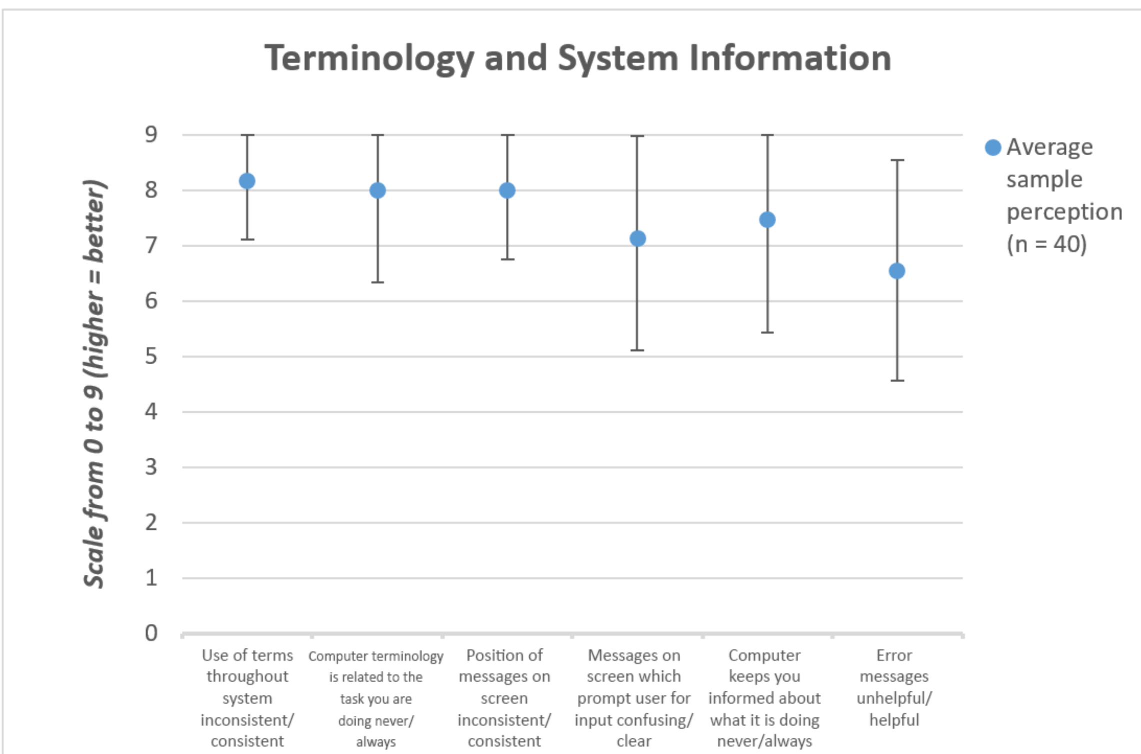


Figure 3.5: QUIS mean results: Terminology and System Information showing standard deviation.

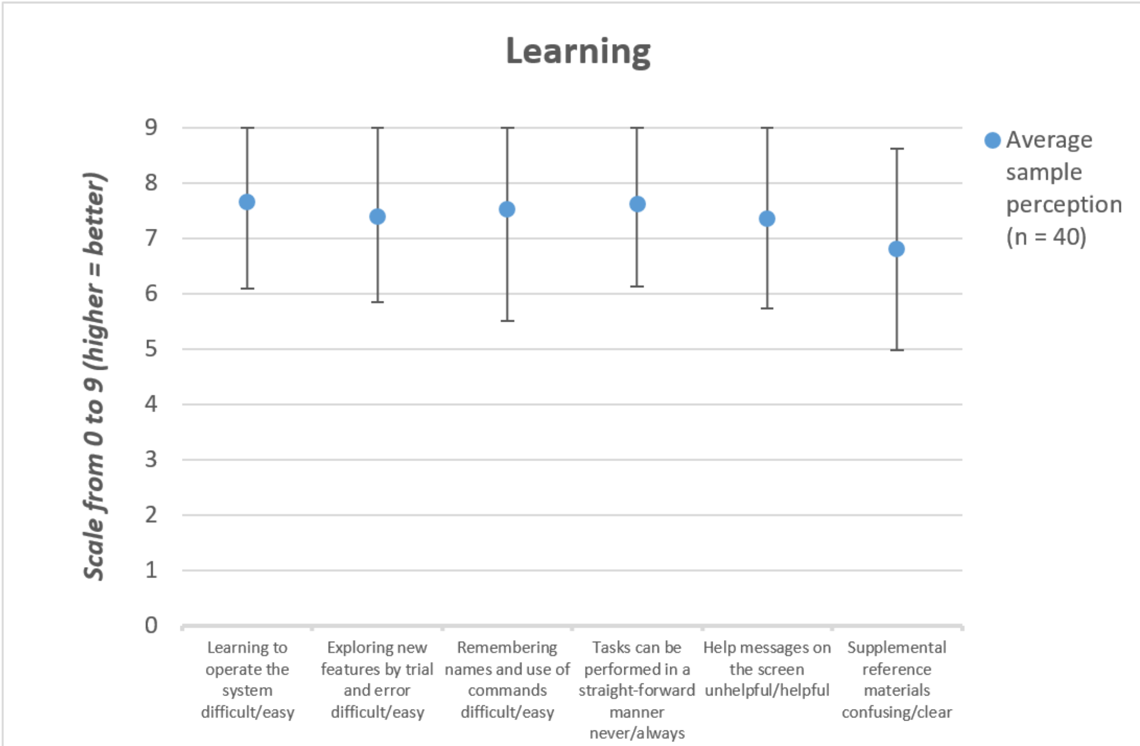


Figure 3.6: QUIS mean results: Learning showing standard deviation.

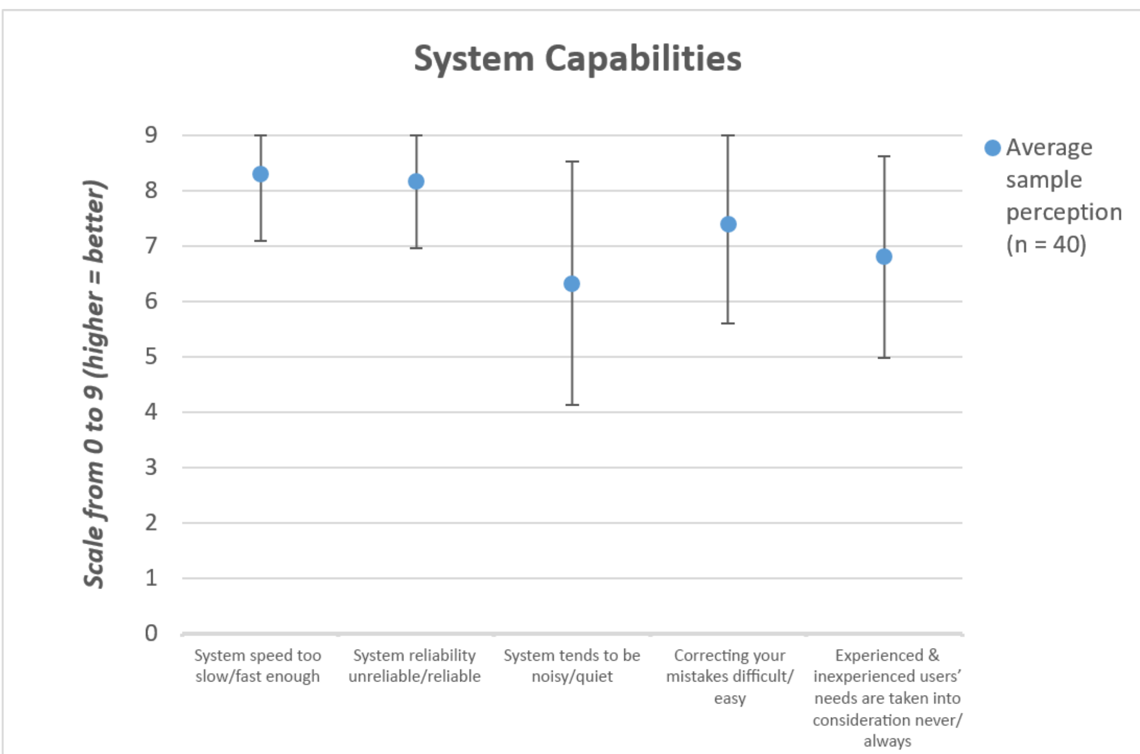


Figure 3.7: QUIS mean results: System Capabilities showing standard deviation.

Overall, these results indicate a high degree of user satisfaction with the game. In particular, participants reported that the game was overall more wonderful than terrible (6.48), and they felt an adequate amount of power within the game (6.08) (Figure 3.3). The highlighting used within the game simplified their tasks (7.35), and the sequence of screens was quite clear (7.28) (Figure 3.4). The terminology and system information was rated highly overall, indicating consistent use of terms (8.18) that always relate to the tasks being performed (8.0) (Figure 3.5). Aspects of learning the system were steady, including the ease of learning the game (7.65) and remembering the controls (7.53) (Figure 3.6). Finally, performance-wise the game was reliable (8.18) and fast enough (8.3), indicating an absence of computer lag or stutter due to poor performance and optimization (Figure 3.7).

Despite these results, the mean scores do highlight some areas of improvement. Participants rated the game as not very flexible (4.7), drawing from the structured nature of the scenario (Figure 3.3). More specifically, trainees are required to complete each objective sequentially to proceed and there is no room given for the trainee to choose their path to success. However, this may actually be beneficial for scenarios which replicate medical procedures that must be followed sequentially with no room given for bypassing steps. There were several messages prompting for participant input which could have been clearer (7.13) (Figure 3.5), such as the first objective's (InStandTarget, OB1) prompt to "Approach the anesthesia machine and inspect the ongoing surgery", and the open-ended feedback mentions specific tasks to iterate upon (see Section 3.7.5). Although error messages received the lowest rating in the terminology and system information section (6.55), this may be due to the absence of error messages within the game altogether (Figure 3.5). When answering the questionnaire, some participants asked for clarification on this question and were instructed to answer it to the best of their ability, prompting mid-ranged responses. One aspect in particular within the system's capabilities stands out, which is the rating for the system's noise or quiet level (6.33) (Figure 3.7). This issue is greatly expanded upon in the open-ended feedback section (see Section 3.7.5).

3.7.2 System Usability Scale (SUS)

The 10-question System Usability Scale returned with encouraging results (Mean = 79.25, SD = 14.85), indicating a willingness to use the system frequently. This result indicates an adequate level of consistency, easy of use, and user confidence in the game as a whole. The game did not suffer from any glaring issues with respect to overall function integration or a need for a technical support person for an average user to leverage during use.

3.7.3 Game Engagement Questionnaire (GEQ)

Summarized results of the different GEQ categories (i.e. (i) immersion, (ii) presence, (iii) flow, and (iv) absorption) are detailed in Figure 3.8-3.10.

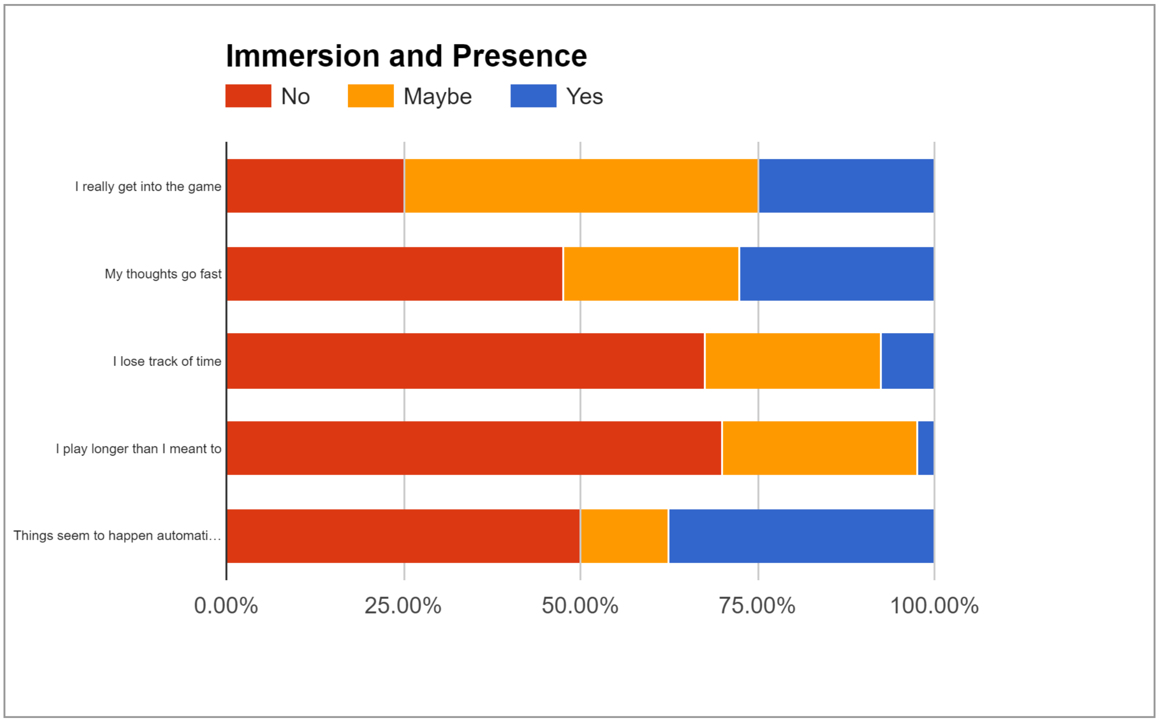


Figure 3.8: GEQ results: Immersion and Presence.

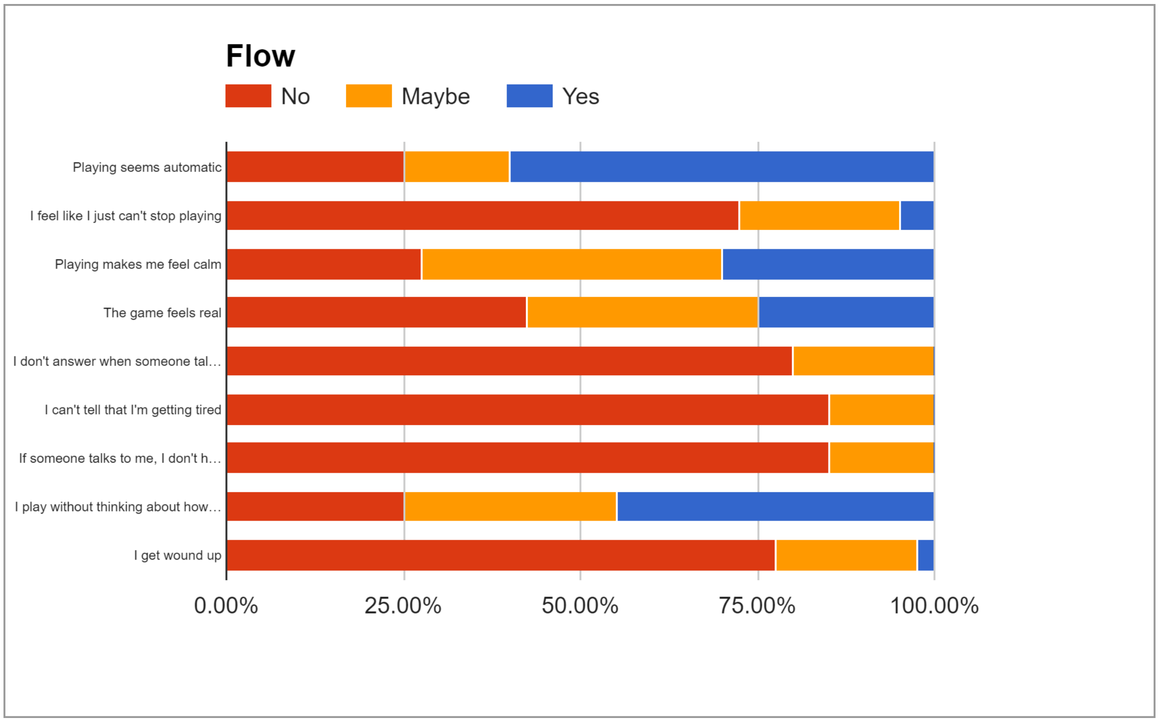


Figure 3.9: GEQ results: Flow.

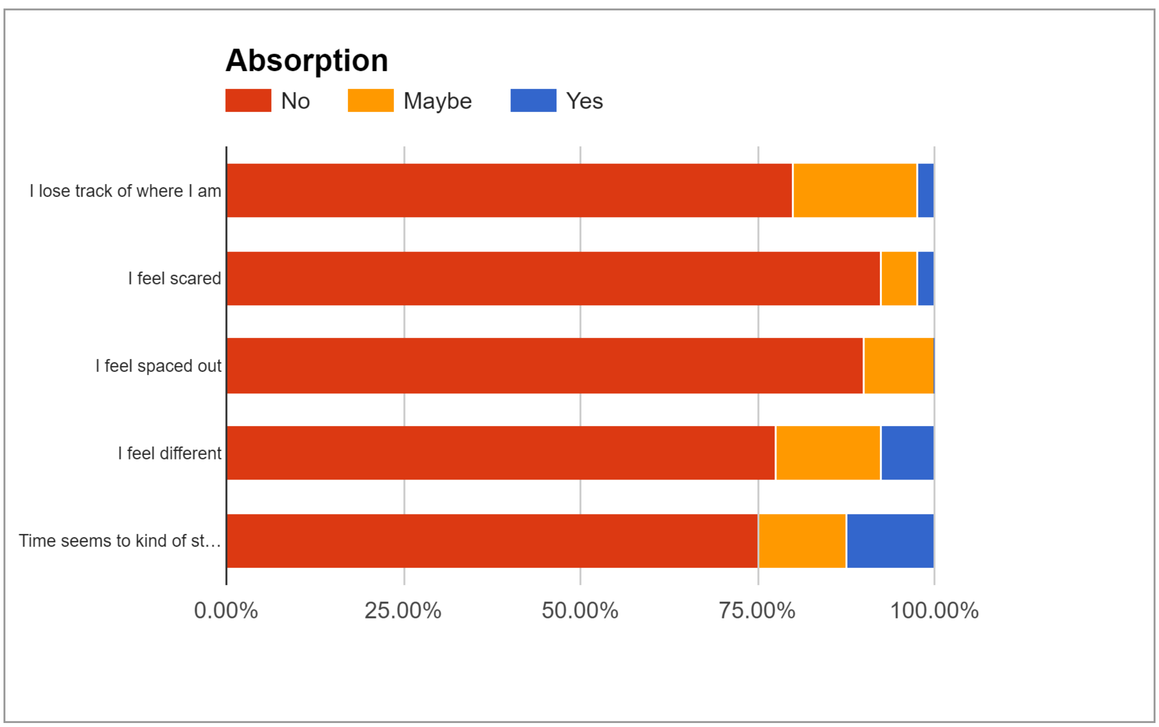


Figure 3.10: GEQ results: Absorption.

Overall, the results of the GEQ indicate a need for improvement across all four categories of engagement. However, the game has the most success in the areas of immersion and presence, which follows Brockmyer et al.'s suggestion that the lower levels of engagement are easier to endorse as opposed to the higher successive levels (ranging from easiest to hardest starting from immersion to presence, to flow, and finally to absorption) [11].

While an equal number of participants disputed their ability to get into the game (25% no, 25% yes), a larger portion remained unsure (50%) (Figure 3.8). However, several participants reported a feeling of presence through fast moving thoughts (27.5%) and actions seeming to happen automatically (37.5%) (Figure 3.8). In terms of flow, playing seemed automatic to many participants (60%) and almost half were able to play without actively thinking about how to play (45%) (Figure 3.9). Furthermore, some participants felt that playing made them feel calm (30%) and that the game felt real (25%) (Figure 3.9). Unfortunately, participants believed that they would be able to tell if someone talked to them while playing (85%) and believed they could answer appropriately (80%), and that they could tell when they were getting tired (85%) (Figure 3.9). Finally, absorption was unanimously the least-felt aspect of engagement. 80% of participants were able to keep track of where they were, and only 7.5% felt overall different after their game play session (Figure 3.10). The most positive result was a feeling of time standing still (12.5%) (Figure 3.10). However, significant iteration remains before a majority of trainees feel an aspect of absorption throughout the game.

3.7.4 Game Metrics

Collected game metrics offer great insight into which objectives were the most difficult for participants to complete. The average game play session lasted 232 seconds, with the fastest participant completing the game in just over two minutes (Table 3.1). A per-objective breakdown of the mean time taken by participants is detailed in Figure 3.11.

Minimum time (s)	128.7
Maximum time (s)	498.4
Mean time (s)	232.7
Standard Deviation	75.3

Table 3.1: Overall play session metrics.

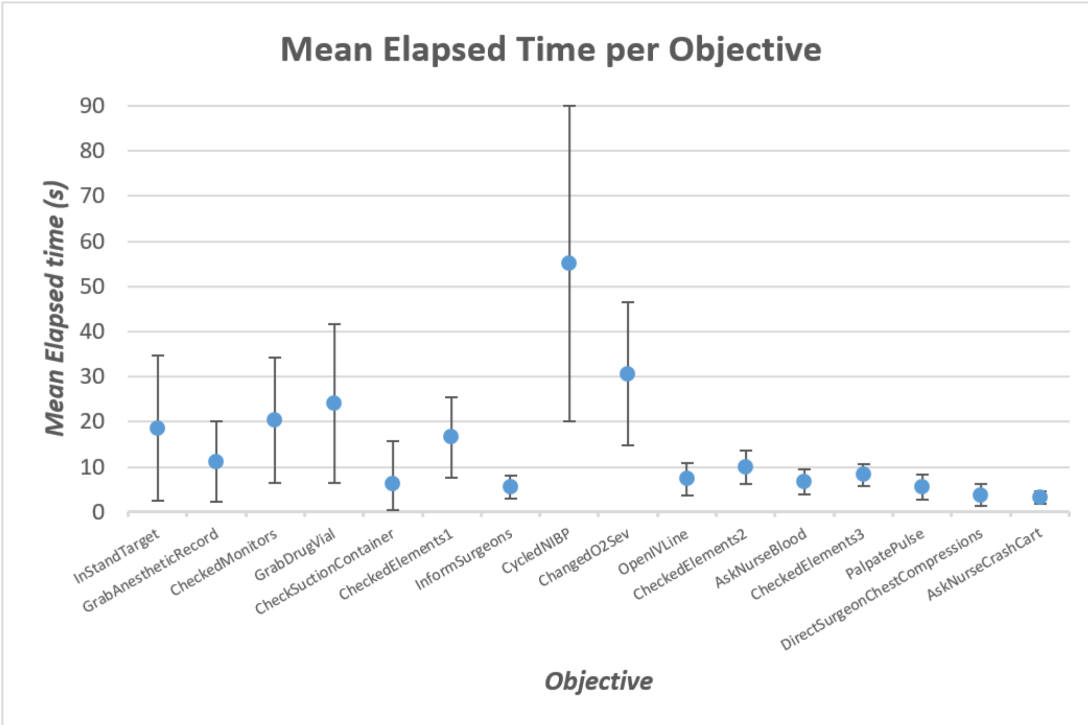


Figure 3.11: Mean elapsed time taken per objective showing standard deviation.

In general, the gradual decrease in time taken per objective in the second half of the game indicates a level of learning throughout game play and ease of use over time. Subsequent similar objectives became quicker to complete, such as CheckedElements1 (OB6), CheckedElements2 (OB11), and CheckedElements3 (OB13)(Mean = 16.5 s, Mean = 9.9 s, and Mean = 8.2 s respectively), further suggesting increased competence through practice (Figure 3.11).

Three particular pain points are worth noticing: the difficulty of the first objective (InStandTarget (OB1), Mean = 18.5 s), the increased time taken to grab the drug vial despite it being the same game play actions as grabbing the anesthetic record (GrabDrugVial (OB4): Mean = 24.0 s, GrabAnestheticRecord (OB2): Mean = 11.1 s), and the trouble many pticipants faced cycling the blood pressure cuff during CycledNIBP (OB8, Mean = 55.0 s) (Figure 3.11).

Despite participants reporting an ease of learning the system and remembering the controls (see QUIS results, Figure 3.6), average completion time for the first objective was higher than expected. This objective contained two elements: moving the avatar to a glowing green spot on the floor, and facing the patient bed. Aspects of the objective were problematic, due to both the clarity of where to stand and the instructions regarding where to look. The target to stand within was a knee-high glowing green cylinder placed on the floor (see Figure 3.12). The target's size and shape proved to be a confusion point, as many participants were unclear whether they could enter the cylinder or simply collide with it. Compounding this, as it is the first objective of the game, game play instructions dictated by the experimenter before play are still fresh in the participant's minds, namely the description of "Objects in the environment which glow green are trying to get your attention - look at them, click on them, or in some way interact with them". Many participants either approached the target without reading the objective first (as the target was large, glowing, and easily noticeable and attention-grabbing in the starting view), or approached the target and tried to instead view and click on it as opposed to standing within it. Furthermore, the wording of the objective was unclear with respect to where to look once standing within the target. The direction to view is described as "inspect the ongoing surgery", though that could be interpreted as one of many things: the patient, the surgeons, the anesthesia machines, or an all-encompassing view of the room in general.

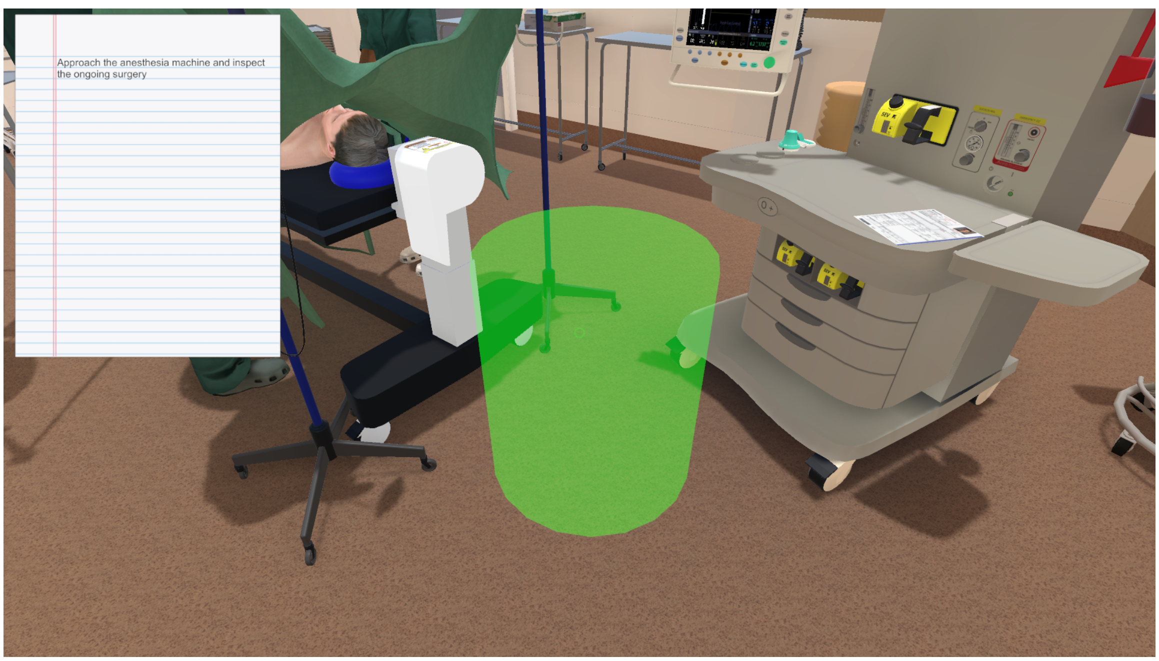


Figure 3.12: In-game view of the stand target during the InStandTarget objective (OB1).

A second issue involved obtaining the drug vial (GrabDrugVial, OB4), even though the participants were able to first learn the corresponding game play action (look at the object and click the mouse), through the previous objective of holding the patient's anesthetic record (GrabAnestheticRecord, OB2). Despite this sequence of learning, participants unanimously took longer to obtain the drug vial as opposed to the anesthetic record. I believe this may be attributed to the size difference between the anesthetic record, which is large, and the drug vial, which is relatively small. An in-game view size comparison is shown in Figure 3.13.

Figure 3.13: In-game view of the anesthetic record (bottom left) and the drug vial (top right, glowing for emphasis).

Further differentiating the anesthetic record and drug vial is their proximity to the trainee's typical current position. Upon the start of the GrabAnestheticRecord objective (OB2), the participant is standing within interacting range of the anesthetic record and focusing the view on it displays the context-sensitive help text of "Grab anesthetic record". However, if the participant does not move before the GrabDrugVial objective (OB4, they are not required to do so as the CheckedMonitors objective (OB3) can be completed without moving), they will initially be too far away to receive either context-sensitive help text or the ability to actually interact with the drug vial without moving slightly closer. These two factors combine to add an unexpected extra layer of difficulty when completing the GrabDrugVial objective (OB4) despite its initially apparent similarity to grabbing the anesthetic record.

Finally, the objective which proved to have the highest learning curve for participants involved cycling the blood pressure cuff using the anesthesia monitors. Despite completing seven previous objectives demonstrating the need to search the environment for glowing green elements to interact with, the buttons on the anesthesia machine were by far the smallest elements to search for (Figure 3.14).

Figure 3.14: In-game view of the anesthesia monitor button (center of view). Zoomed-in view has been placed on the bottom right for added clarity.

Adding to the problem, was the possibility that many participants did not understand what "cycl[ing] the blood pressure cuff" to mean. To participants unfamiliar with the terminology of a blood pressure cuff, many may not have known how to proceed. While participants who were not enrolled in a Health Sciences program averaged a 57.3 second completion time, the Health Sciences students averaged a significantly faster 42.0 second completion time, indicating that a minimum basic knowledge or familiarity with typical healthcare hardware may significantly reduce problem points while playing the game. Finally, neither the participants from the Health Sciences programs or participants from other programs were necessarily familiar with an anesthesia machine, monitor, or its use to cycle a blood pressure cuff, indicating the significance of terminology used with respect to the blood pressure cuff itself.

3.7.5 Open-Ended Questions

Detailed in this section are common responses to the open-ended feedback questions at the end of the questionnaire. Many of these responses expand upon the problems revealed in the responses to the QUIS, SUS, GEQ, and game play metrics, yet also offer insight into what aspects of the game are working well and should be kept.

10 participants (25%) mentioned an ease of use and familiarity with the controls, echoing the positive results from the QUIS (see Figure 3.6). The controls were de-

signed to mimic those of traditional computer-based first-person shooter video games (WSAD keys to move, mouse to look around), which seems to have provided participants a low barrier of entry to begin play.

> *"It felt more natural since it fit the standard wsad and mouse movements of most games."*
>
> *-Participant 15 (24th October, 2016)*

> *"The controls felt intuitive for me, although I'd say I was already familiar with them."*
>
> *-Participant 30 (31st October, 2016)*

The visual accuracy of the room elements and layout was mentioned by 18 participants (45%) as natural, intuitive, or realistic. The creation of the 3D models and textures which comprise the operating room and its elements represent the longest period of development, and seems to have paid off. This also highlights the importance and value of high quality reference images and videos of real-world settings if developers are looking to recreate an environment virtually.

> *"I think the consistency and accuracy of the medical instruments helps the learning process."*
>
> *-Participant 5 (19th October, 2016)*

> *"As far as I could tell, this was an accurate showing of a surgical room."*
>
> *-Participant 36 (3rd November, 2016)*

The scenario itself and the steps within it seemed to resonate with participants, as six (15%) mentioned either its intuitiveness or the benefits a realistic representation of real-world processes might provide. Working together in a multidisciplinary team with medical experts has clearly been a benefit, as Dr. Alam and Dr. Lee's development and validation of the scenario illustrates.

> *"The series of actions performed during the procedure seemed reflective of the actual work environment. The game create[d] a sense of urgency while playing."*

-Participant 13 (24th October, 2016)

"It was interesting to see a simulation from the perspective of those who work to save, or aid lives."

-Participant 26 (28th October, 2016)

Finally, the background ambient sounds and noises were also described as realistic by nine (22.5%) different participants.

"The sounds were a nice touch. Good background "ambiance", if I can call it that."

-Participant 1 (18th October, 2016)

"I think the setting and ambient noise works well to create immersion, even without motion or a great amount of feedback."

-Participant 5 (19th October, 2016)

Participant 5's response in particular demonstrates the ability of audio cues to contribute to overall game visual quality perception, a field of study explored extensively by Kapralos et al. [51, 83, 84, 21, 22]. For example, Kapralos et al. investigated the use of customized audio within serious games and the potential benefit it may provide, concluding a potentially strong effect of sound on visual fidelity perception and task performance [51]. This perception of visual realism may include varying texture resolution or model polygon count, and holds accurate when including stereoscopic 3D displays [83, 84]. This was expanded upon by Cowan et al. in studies exploring both spatial audio cues and background sound in virtual cognitive surgical skills training, with results indicating that the appropriate use of sound can lead to performance improvements when performing a task within a virtual environment without a corresponding decrease in the perception of visual realism [21, 22].

The various issues revealed through the QUIS, GEQ, SUS, and game metrics were explained in detail throughout participants' open-ended feedback. One possible solution was suggested to fixing the lack of clarity with the first objective (the InStandTarget objective (OB1)), namely by splitting it into more detailed subsections.

"Consider splitting the very first objective into 2 (or a sub checklist like some of the monitor checking is). It's the only objective in the game with multiple requirements that are obfuscated (even if only slightly. 1)be here and 2) click the man)."

-Participant 5 (19th October, 2016)

While I believe this to be a possible fix particularly considering the fact that objective sub-checklists are already utilized in the game, this will likely remedy the clarity of instructions given yet the issue of a strange size and shape to the stand target would remain. Further discussion and a new design is presented in Section 3.8.

The slower objective completion time of the GrabDrugVial objective (OB4) compared to the GrabAnestheticRecord objective (OB2) was also mentioned, as well as an interesting suggestion to solving the issue based on the drug vial's smaller size.

> *"The first time that the game asked me to find something small (the drugs), I did not know where to look for them. Perhaps it would help to direct the player's attention in the direction of the drugs using another task, and then the drugs will already be in their line of sight when they are asked to find them."*
>
> *-Participant 20 (26th October, 2016)*

Although including an additional objective before grabbing the drug vial may ease the difficulty of finding it in the virtual operating room, changing the content of the scenario to offer perhaps more 'game-like' guiding tasks might negatively skew participants' perceptions that the game feels real (57.5% of participants were either undecided or felt that the game was real; see Figure 3.9). However, changing the order of existing objectives to better direct the trainee's attention towards the drug vial may be an option, and is implemented in Section 3.8.

One problem widely mentioned was the small size and difficulty finding the anesthetic monitor buttons during the CycledNIBP objective (OB8), the objective with the highest mean completion time (55.0 s, see Figure 3.11). Participants (10, 25%) cited the button's small size and non-attention grabbing glowing highlight.

> *"The highlighted green things need to be more obvious as I got lost looking for which buttons to press on the monitors."*
>
> *-Participant 1 (18th October, 2016)*

> *"Allow the user to zoom in with Mouse2. It'll make it a lot easier to look at the monitor screens."*
>
> *-Participant 7 (20th October, 2016)*

The suggestion to implement a zooming function is useful, as participants also cited a difficulty with positioning themselves properly in front of the monitors. 11 participants (27.5%) described the movement of the avatar as clunky, loud, or too fast to control.

> *"Walking felt very heavy. I had less control than I was comfortable with while walking around the environment. Pressing the "move" keys down result in a much greater distance covered than I expected. As in, each step seemed very long."*
>
> *-Participant 13 (24th October, 2016)*

> *"I think a slow walk or a key you could press that would enable smaller movements would work, I found it was a bit difficult to get in to the right position in front of the monitors. Also the character could move a bit slower to help with it as well."*
>
> *-Participant 23 (27th October, 2016)*

The combination of a zooming function with a slow walk key could alleviate the issues with fast character movement speed, difficult positioning, and the readability of the smaller monitor buttons. These changes are developed in Section 3.8.

Finally, the most cited issue that participants discussed dealt with the game's lack of character animation affecting their sense of immersion and realism of the virtual environment. 18 participants (45%) mentioned objects instantly moving from one place to another instead of smoothly transitioning or the absence of animation from the other surgeons in the environment.

> *"Everything in the room felt very static and you often felt frozen in time when playing."*
>
> *-Participant 6 (19th October, 2016)*

> *"The stillness of all the other figures in the room felt unnatural."*
>
> *-Participant 10 (21st October, 2016)*

> *"Many interactions were to simply click and something would change instantly, causing it to not feel very realistic. For example, picking up the patient information would instantly appear in front of my face."*

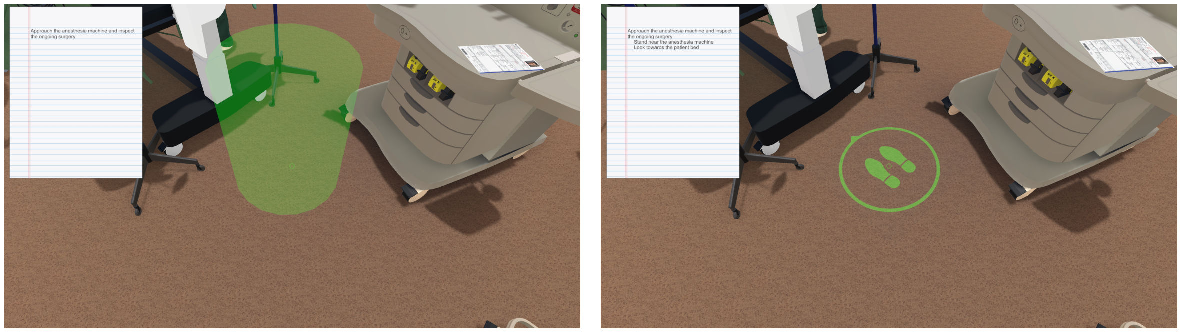
-Participant 16 (25th October, 2016)

I believe the lack of animations to be the single largest contributor to the mediocre results seen from the GEQ. As the virtual environment and scenario was meant to replicate a medical crisis situation, the lack of animation created a sense that the game felt very static, which might also contribute to the participants rating the overall system as quite rigid in the QUIS (Mean = 4.7; see Figure 3.3). The game being unable to convey this sense of crisis would be a poor reflection of the real-world situation being simulated, which is a missed opportunity that the utility of serious games can provide. Character animations were omitted from development due to the additional time it would take to create. However, the next iteration of the game throughout future work should prioritize this. Thankfully, as detailed in Section 3.8, there are smaller changes to polish that can be made immediately.

3.8 Iterative Development

An initial round of iterative development was conducted to remedy many of the issues discussed previously. Among these are i) clarifying the InStandTarget objective (OB1), ii) reordering the objectives to transition more smoothly to the drug vial during the GrabDrugVial objective (OB4), iii) implementing a zoom function and slow walk button, iv) changing the avatar's movement speed to be slower, and v) animating the grabbing of the anesthetic record.

Previously, the stand target for the trainee during the InStandTarget objective (OB1) was a large transparent cylinder, which wasn't able to communicate whether i) the trainee should stand within it, and ii) the direction to look towards once standing within. Instead, this has been replaced with a texture situated directly on the floor. The texture is a simple circle with a small arrow pointing towards the patient bed and a set of shoe prints in the center of the circle; see Figure 3.15 for a visual comparison of the designs.



(a) The original stand target (b) The modified stand target

Figure 3.15: Iteration of the stand target during the InStandTarget objective (OB1, (a) pre and (b) post). Also displays the two new sub-objectives in the top left.

The modified stand target helps communicate both the need to stand within it and look towards the patient bed in three ways, i) having a flat image on the floor affords the interaction of clicking on it as a physical object much less than a knee-high cylinder does, ii) the set of shoe prints implies a need to stand on top of them within the circle, and iii) the direction of the shoe prints as well as a small arrow on the outer edge of the circle communicates the direction to look towards the patient bed. I believe this design will be much more intuitive to trainees and substantially reduce the average InStandTarget objective completion time. Furthermore, as per one participant's suggestion, two additional sub-objectives have been added to the InStandTarget objective (OB1) to help clarify the two separate requirements for completion. These sub-objectives update dynamically and allow the trainee to see whether they are accomplishing neither, one, or both of them at any time.

To help draw attention to the drug vial during the GrabDrugVial objective (OB4), objectives Two and Three (GrabAnestheticRecord and CheckedMonitors respectively) have been reversed. Previously, the trainee was requires to look right to obtain the anesthetic record, then change direction and look left to check the monitors before finally looking right again to obtain the drug vial. By switching these two objectives, the trainee does not have to look left or backtrack to the right within the first four objectives of the game. Ideally this change will help naturally direct the trainee's attention towards continuing to look right to more easily find the drug vial within the virtual environment.

In an effort to address the difficulty in finding the correct monitor buttons to press during the CycledNIBP objective (OB8), one participant's suggestion to implement a zoom function has been added. Internally, this is accomplished by decreasing the first-person camera's field of view to 25 degrees as opposed to the regular 60 degrees.

As the game's keyboard controls were designed from the outset to mimic first-person shooter video games, the zoom has been mapped to holding the mouse right click button which in typical video games with guns acts as a zoom or scope option. It is anticipated that this new ability will aid trainees with exploring and feeling situated within the virtual environment in general and increase the feeling of engagement.

Following the many participant comments regarding the rapid speed of character movement, the avatar's speed has been decreased to two thirds of what it was originally. Additionally, a slow movement button has been added when the trainee wishes to navigate tight areas or approach objects in the environment in a very controlled manner. The Shift key was chosen for this as it typically represents a modifier to movement speed in other video games.

Finally, the static and 'snapping' nature of elements in the environment has partially been addressed. As animating the human characters within the environment requires considerable resources, iteration time was instead focused on the smaller interactions that the trainee takes themselves. As Participant 16 noted, grabbing the anesthetic record caused it to instantly shift position and rotation to a predefined snapping point parented to the participant's viewpoint. The highest fidelity fix may involve animating a set of hands representing the trainee's avatar picking up the anesthetic record realistically. In a study analyzing the influence of movement feedback given to users in a virtual rehabilitation system, Albiol-Perez et al. found that when given movement feedback in the form of moving virtual feet, users felt more immersed and had a better sense of presence in the virtual environment [2]. Due to development resource limitations, a mid-way solution has been implemented in a significantly shorter period of time. Instead of instantly shifting position and rotation upon being grabbed, the anesthetic record now smoothly interpolates to its snapping point (and back to the table when released) over a period of 0.4 s using a quadratic ease-in-ease-out formula.

$$i = c \times (t/d)^2 + b$$

Where i is the interpolated resultant value, t is the elapsed time, b is the lower bound, c is the total range, and d is the total duration.

This creates a movement and rotation curve that slowly eases into a transition while accelerating out of it near completion. While the trainee character's hands aren't represented, this interpolation eliminates the immediacy of an instantaneous snapping movement and will hopefully contribute to a reduced sense of a static environment.

3.9 Study Discussion

Following the results of the usability study and iterative development, it is necessary to reflect on the study's hypotheses, namely:

- Minor usability issues exist within the game's interface or game play.
- The game is engaging for the participant to play.
- The game feels realistic, especially regarding the visuals and audio.

Several usability issues were discovered within the game's interface and game play, and unexpectedly in the controls as well. The InStandTarget objective (OB1) had unclear instructions on both the interface and within the virtual environment, for example, and a fast moving virtual avatar created issues with the controls. Fortunately these issues were minor and could be corrected through rapid iteration, and none of the usability problems led to the serious game being completely unplayable (see Section 3.8).

Although the serious game saw some success with game engagement in the areas of immersion and presence, it did not seem to induce a feeling of flow or absorption in the majority of participants (see Section 3.7.3). Part of this may be due to various usability issues discussed previously and iterated upon, though future work should prioritize reducing the feeling of the game being rigid in order to promote engagement.

Finally, many participants agreed that overall, the game felt realistic, especially noting the high fidelity of visuals and inclusion of audio (see Section 3.7.5). This fidelity and feeling of realism may have been partly responsible for any positive game engagement that participants felt, although as previously discussed, this still requires improvement.

3.10 Future Work

For all of the positive effects that this iteration of changes may promote, further work still needs to be completed before the ACLS serious game is ready to be 'delivered'. More specifically, the inclusion of fully animated human characters within the virtual operating room may greatly reduce or entirely eliminate the game's response as feeling static to many trainees, and increasing the use of contextualized audio cues may help this too. Having fully voiced surgeons which react to changes in the scenario and the completion of objectives would create a much more dynamic simulation, and trainees may feel that they were truly conversing with the surgeons instead of simply clicking on them and giving them orders to fill. Further iterations of user testing will benefit from more game play metrics such as tracking the trainee's movement and view direction continuously throughout the game, and testing end-users (anesthesia residents) could give insight into the difference in usability between beginner trainees with no medical knowledge and expert trainees with significant background. As this study focused primarily on usability, a further study investigating learning outcomes and material retention must be performed as well.

Finally, the ACLS serious game will be transitioning to a VR implementation, the implications of which are explored through a second study outlined in Chapter 4.

3.11 Recommendations for Designers of Serious Games and Virtual Simulations

Developers of serious games and virtual simulations from both a software-design and scenario-design perspective can stand to heed the lessons learned through the creation of the ACLS serious game. Below I outline five recommendations that have been drawn from my personal experience and from the results of this initial usability study.

- *Interdisciplinary Team*: Both software-developers and traditional educators interested in developing serious games or simulations should strive to work in an interdisciplinary team. The diversity of game design, software development, traditional education, and content expert experience will only strengthen the project from as many angles as possible. All of my previous work involving serious games and simulations for healthcare education (see Section 2.6) were made possible due to strong collaborations with healthcare content experts who were looking for modern learner-centric approaches to education.

- *Graphical and Audio Realism*: Much of the development time of the ACLS serious game was spent producing high-quality 3D models which were accurate to a real-world location being simulated. The most frequently occurring positive feedback received from participants was about the accuracy and fidelity of the virtual environment, demonstrating its importance to trainee satisfaction and engagement. This would have been much more difficult without the collection of high-quality reference images and videos. Background audio cues were also appreciated, and the future inclusion of voiced virtual characters is expected to follow this trend. However, it is important to note that although high fidelity is appreciated by participants, evidence suggests that higher fidelity will not necessarily lead to greater learning and requires significant resources to implement

[21, 22, 51, 83, 84]. Despite this, and where possible, devote resources to aim for graphical and audio realism as the project requires.

- *Usability Options*: In the initial testing version of the game, overall participants felt the game to be rigid and not particularly engaging. Part of this may be due to a lack of usability options for trainees to utilize, such as an alternate walking speed or ease-of-use zooming function. Aim to include usability options for the most commonly performed tasks within the serious game and simulation, even if the majority of trainees may not take advantage of them in the end. Giving trainees the power of choice is a key game design principle that is relatively easy to design and implement.

- *Standardized Controls*: While designing the trainee interactions, conform to standardized controls as much as possible. Participants believed in a quick and easy way to remember the learning curve which helped quickly transition them into game play. Following traditional video game control patterns let many participants feel comfortable and familiar with what they were playing.

- *Prioritize Usability*: Although the study described here found a low level of game engagement, I suspect a portion of this issue can be attributed to the various usability issues discussed extensively above. Unclear objectives, confusing game play elements, hard to see small items, and a trainee avatar which moved too quickly throughout the environment were many small issues which added together to create a larger problem with player engagement. These problems were also easily discoverable through user usability testing and rapidly fixable. When developing serious games and simulations, test for usability first and foremost as it may have a significant effect on the overall game engagement and learning outcomes.

3.12 Summary

In this chapter I have discussed the development of a serious game for anesthesia crisis resource management skills which aims to promote an engaging learner-centric approach to medical education. An initial usability study was conducted with 40 participants ranging from a Game Development to Health Sciences specialization, and the results were analyzed to pinpoint current issues. A round of iterative development was undertaken based on these results, and the changes and rationale behind them was outlined. Finally, the game and usability study's outcomes were summarized in five separate recommendations for the developers of other serious games and simulations to build upon in the future.

Chapter 4

Epidural Preparation Serious Game

4.1 Overview

The second serious game developed as part of this thesis facilitated a comparison between seated and room-scale VR. To this end, I developed a serious game (the epidural procedure preparation serious game) that will be used to measure the trainee's subjective usability satisfaction and performance within both a seated and room-scale virtual reality setup while completing the task of preparing to perform an epidural procedure. Trainee performance was measured along three categories: i) memory, ii) task completion time, and iii) spatial distance estimation. The scenario of preparing for an epidural procedure (i.e., where a drug or contrast agent is injected directly into the epidural space of the spinal cord), was chosen as it highlights the need to move around within the environment, read detailed patient information before the procedure, and obtain and manipulate small objects within the room. Furthermore, the scenario can be developed further in the future to include actually performing the epidural procedure itself.

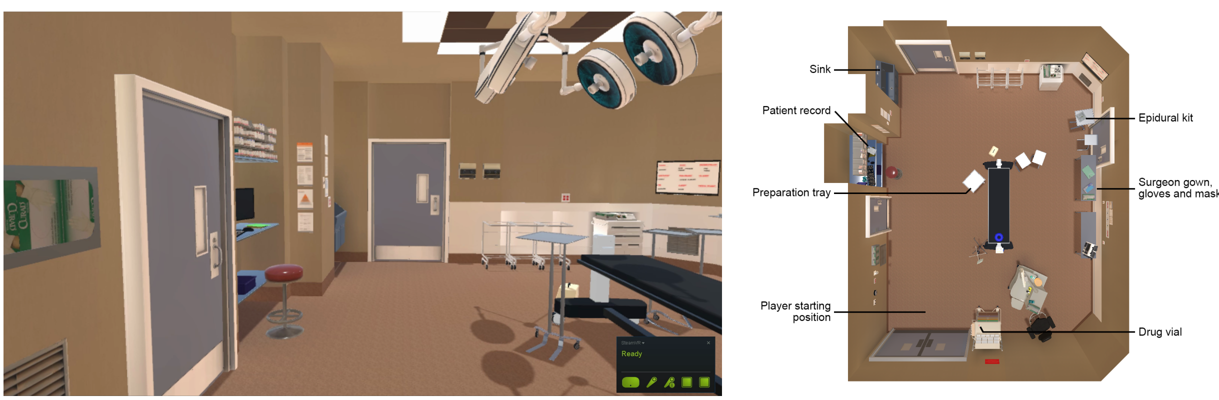
The scenario was developed alongside Dr. Alam's content expertise while the preliminary integration of the HTC Vive virtual reality system into the game engine was completed by Minh Nguyen from UOIT. The extent of Mr. Nguyen's assistance is limited to importing the relevant software plugins into the Unity 3D game engine (discussed in further detail in Section 4.2).

4.2 Game Description

In the epidural preparation serious game, the trainee assumes the role of a medical professional preparing to perform an epidural procedure. This involves reading a detailed patient anesthetic record, washing their hands, wearing proper surgery clothing, and gathering the various tools needed for the procedure and placing them onto a preparation tray.

The game is set within the 3D virtual operating room environment from the ACLS game described in Chapter 3. However, in this version of the game, the surgeons have left the room and the patient bed is empty. The trainee uses the HTC Vive virtual reality HMD with the game, wearing the stereoscopic 3D headset while using a pair of hand-held motion-tracked controllers. The game can be played in both a seated and room-scale configuration. The seated setup is achieved by sitting and remaining in a chair in the center of the tracked play space.

As detailed with the ACLS game (see Section 3.2), the epidural game was developed using the Unity 3D game engine while Autodesk Maya was used to develop the 3D models. Adobe Photoshop was used to create textures for both 2D elements and 3D models, and particular attention to detail was taken to accurately replicate the physical characteristics of a real-world operating room in the Sunnybrook Health Sciences Centre, in Toronto, Canada. An example of this replication can be seen in Figure 3.1. The SteamVR Plugin and SteamVR Unity Toolkit plugins (obtained from the Unity Asset Store), were used to facilitate integrating the device and controller interactions within the Unity 3D game engine [117, 109, 115]. A view of the environment including a top-down layout is provided in Figure 4.1.



(a) In-game first-person view (b) Operating room top-down layout

Figure 4.1: Virtual operating room.

Throughout the scenario, the trainee completes seven objectives which involve moving within the room and using the motion controllers to touch and hold different objects within the environment. Elements within the environment that the trainee is intended to interact with pulse a glowing green color to indicate their importance.

To better understand the significance of the usability results, each objective (OB) in the scenario is briefly outlined below.

- OB1) GrabAnestheticRecord: The trainee moves from their starting position to the computer desk and holds the patient record on the table.
- OB2) UseSink: The trainee moves to the sink and interacts with the faucets.
- OB3) GrabGown: The trainee moves to the side table and interacts with the surgical gown, gloves, and mask boxes.
- OB4) GrabEpiduralKit: The trainee moves to the epidural kit and holds it.
- OB5) PlaceEpiduralKit: The trainee moves to the preparation tray and places the epidural kit on it.
- OB6) GrabDrugVial: The trainee moves to the anesthesia cart and holds the drug vial.
- OB7) PlaceDrugVial: The trainee moves to the preparation tray and places the drug vial on it.

The trainee's controls are mapped to the buttons of the HTC Vive hand controllers and include: i) displaying an objectives list, ii) teleporting within the virtual environment, and iii) interacting or holding virtual objects. The trainee's objectives are shown in a list which is attached to their left hand controller and resemble a sheet of paper with notes written on it (Figure 4.2). This list can be toggled ON and OFF with the left controller's grip button, while viewing the list is a similar motion to checking the time on a watch worn on your left hand.

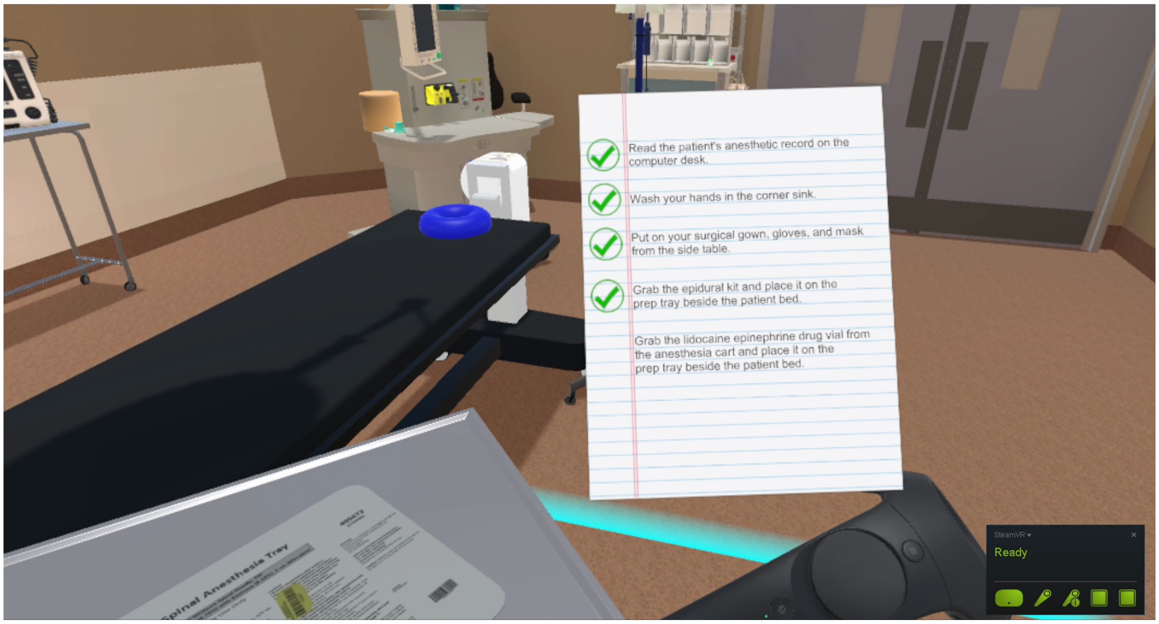


Figure 4.2: In-game view of the objectives list currently displaying all of the completed objectives plus the one in-progress. The list is parented to the trainee's left controller (bottom right).

Although the trainee may freely walk around the virtual environment within their real-world play area, they may also teleport themselves throughout the virtual environment using the trackpad on their left hand controller. Pressing the trackpad activates a laser pointer being projected from the trainee's left hand controller and the game world displays a new green grid on the floor (Figure 4.3). Pointing the laser onto the floor grid and releasing the trackpad instantly teleports the trainee's current position onto the targeted floor point, allowing the trainee to freely explore within their new reach. Releasing the trackpad while the laser is not pointing to the floor grid will not allow teleportation, as the floor grid denotes valid areas for the trainee to move within. This was configured to restrict the trainee accidentally teleporting outside of the game environment or within many of the free standing objects (such as the patient bed) within the scene. Although teleportation is not a feasible real-world action which trainees would be used to, the teleportation mechanic has been widely adopted by VR games developers as a viable method of first-person avatar movement [119, 20, 58]. This may be due to owners of the HTC Vive overwhelmingly preferring teleportation-based movement compared to artificial locomotion which may easily induce nausea [59].

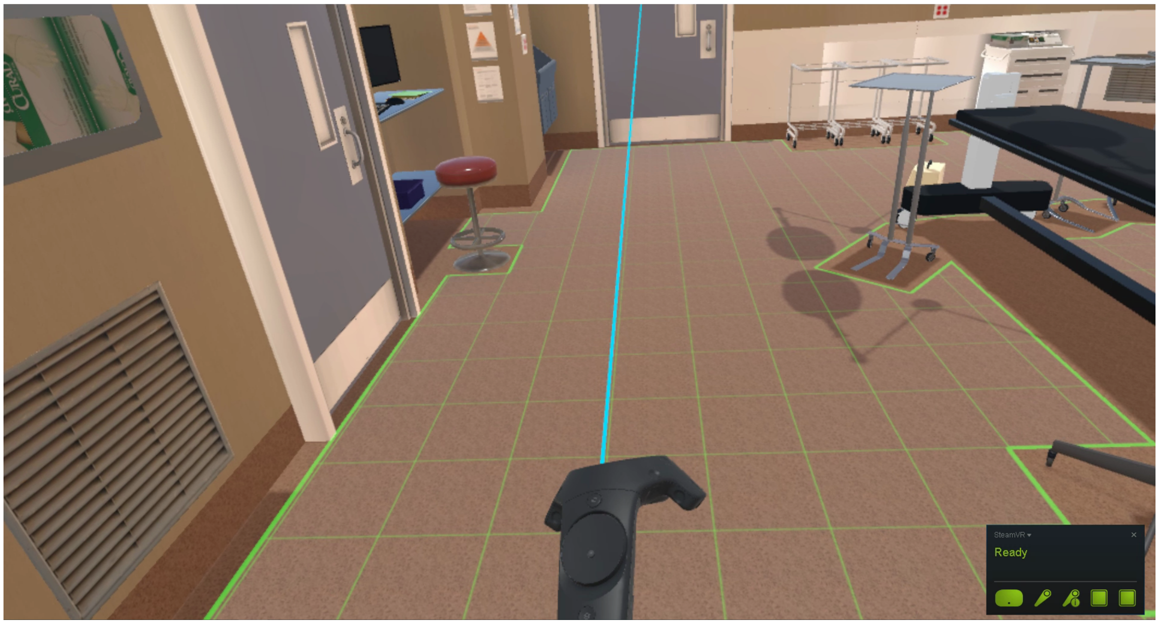


Figure 4.3: In-game view of teleporting. The controller (bottom middle) projects a laser pointer into the environment, and a valid targeting area appears on the floor.

Finally, trainees may interact and hold virtual objects with either of their controllers' trigger buttons. To grab an object, the trainee moves their controller to touch the object and holds the trigger; while releasing the trigger will free the object from their grip and allow the game's gravity physics to affect it. Although this action is ambidextrous (supported on both controllers), displaying the objectives list and using the teleporting mechanic is restricted to the left hand controller only.

The game is void of any background sound and auditory cues, and nothing in the environment moves without direct intervention of the trainee. For example, the computer and anesthesia monitors are blank and objects only move when the trainee is holding them in one of their virtual hands. Background ambient sound was omitted as it would not have been spatialized in the virtual environment, but instead a monaural sound irrespective of the trainee's view direction. An example is the sound of air ventilation ducts in the ceiling which would seem to originate from all angles irrespective of the trainee's ears. Object interaction sounds were omitted as they would require a significant amount of assets to develop. For example, each type of object collision (such as a plastic epidural kit falling onto a laminated floor) would require a different sound effect.

4.3 Study Design

The usability study used a within-subjects design and participants played the game within both experimental conditions, with each game play session followed by an administration of a questionnaire. The two conditions were whether the game was played using a seated or room-scale VR setup, and the order in which each condition was presented to participants was counterbalanced to account for any possible learning effects that may have occurred due to playing the same scenario twice. Furthermore, two separate sets of patient information was used to change the anesthetic record within the scenario across conditions (see Figure 4.6), resulting in four separate participant groups depending on which condition was presented first and which set of patient information corresponded to each condition. Participants were assigned into each group and balanced throughout, resulting in each group containing 1/4 of the total participants. The four participant groups are detailed further in Table 4.1. For example, group A were first presented with the seated VR game setup which contained the anesthetic record information of Patient 1, followed by the room-scale VR game setup which contained the anesthetic record information of Patient 2.

		Anesthetic Record	
		Patient 1	*Patient 2*
VR	*Seated*	A	B
	Room-scale	C	D

Table 4.1: The four participant groups (A-D) based on counterbalanced conditions.

4.4 Hypotheses

The epidural preparation serious game usability study was conducted in order to answer four main questions: i) are there usability issues within the game interface, controls, or game play, ii) is the game engaging, iii) does the game feel realistic and intuitive, and iv) what affect does the difference in VR system setup (seated or room-scale) have on game engagement and trainee performance with respect to memory, task completion time, and spatial distance estimation. Hypotheses for the results of the testing are as follows:

- Minor usability issues exist within the game's interface or game play.
- The game is engaging for the participant to play.

- The game feels realistic, especially regarding the visuals.
- Room-scale VR has a positive effect on game engagement and participant performance within the three categories of memory, task completion time, and spatial distance estimation.

4.5 Participants

The usability study recruited the same participants as those from the ACLS serious game usability study (see Section 3.4) and both studies were completed within one session lasting an average of 45 minutes. The order of which study each participant completed was counterbalanced to avoid the effect of possible study fatigue or learning effect between the two serious games.

A total of 40 participants participated in the usability study, eight of which were female. Participants were staff and students at UOIT aged 18-30, with the majority being 18-20 (35%) or 21-23 (32.5%). Participants were particularly recruited from both the Game Development and Entrepreneurship (GDE) undergraduate program and numerous Health Sciences undergraduate programs in an effort to gain both usability experts as well as end-user perspectives. The GDE students are formally trained in methods of usability and user experience with respect to software and video games, and the Health Sciences students represent the end users of these types of serious games for healthcare. 15 participants (37.5%) were from the GDE program and six (24%) were from various Health Sciences programs encompassing Kinesiology, Human Health Sciences and Medical Laboratory Science. Participants who were not from either of these two programs were staff or students in different disciplines. Participants enrolled in the study voluntarily and were not compensated for their participation. The experiment was approved by the Research Ethics Board of UOIT with reference number 14-129.

4.6 Experimental Procedure

The experiment took place in the Game Science Lab at UOIT and only one participant participated in the experiment at a time. The Game Science Lab was laid out with a small desk and office chair facing a large television. The computer keyboard and mouse was placed on the desk. Participation in the study involved only a single session and did not require performing any additional activities outside of the duration of their session. No additional material was required, and an experimenter was in the room with them at all times. The table and chair were used when the participant was answering the feedback questionnaires, and during this time the experimenter remained behind a cubicle wall separating the play area from the data collection area. Before each play session the chair and table were removed to completely clear the central open space of the room and the experimenter was in the play area managing the cable connecting the HTC Vive to the computer. The open play space measured 3.05 m x 2.43 m (see Figure 4.4 for a view of the Game Science Lab).

Figure 4.4: Room layout of the Game Science Lab with HTC Vive user.

Participants were first welcomed into the lab and asked to sit at the desk. After explaining the experiment, methods of data collection and participant rights, consent was obtained. The study began with a Randot Stereo test to make sure all participants had stereo-vision [107]. Participants who failed the Randot test were informed that their results would not be used but they were allowed to proceed with the study if they wished. Participants were then asked to complete a demographics questionnaire brought up on the monitor (Appendix 4). After completing the questionnaire, the experimenter removed the table and chair and explained the HTC Vive headset and how it should fit on their head. The experimenter explained the adjustable head straps and participants were given time to fit the headset properly to their head (see Figure 4.5). The experimenter then explained the headset's knob to adjust the device's interpupillary distance (IPD) and the participant was given time to adjust it to their optimal visual preference. The participant was given the two HTC Vive motion controllers and fitted with a pair of stereo headphones. The SteamVR Tutorial program, whose purpose is to teach players about the system and how to use the controllers [118] was then launched. Participants completed the tutorial taking an average of five minutes.

Figure 4.5: HTC Vive system description.

The experimenter then explained the purpose of the game and the controls before preparing the room as necessary based on the participant's first experimental condition (for example, the chair was brought in and participant seated if their first condition was seated VR). The experimenter opened the game and asked participants to begin whenever they were ready. The game play session lasted a maximum of 10 minutes. When the game play session was completed, the chair, table, computer keyboard, and mouse were brought back into the room and participants were asked to complete a feedback questionnaire displayed on the monitor (see Appendix 5). After completing the questionnaire, the participant's second experimental condition began along the same lines until the feedback questionnaire was answered for a second time. Finally, participants were thanked for their time and asked whether they had any questions.

4.7 Methods

The feedback questionnaire was comprised of several different questionnaires widely used to assess the usability of user interfaces and game engagement: the Questionnaire for User Interface Satisfaction (QUIS), the System Usability Scale (SUS), and the

Game Engagement Questionnaire (GEQ). The feedback questionnaire also contained open-ended questions specific to the epidural preparation serious game to obtain the participant's subjective opinions on the game's perceived realism and intuitiveness. For a full explanation of the QUIS, SUS, or GEQ, see Section 3.6.

The questionnaire also contained a short five question quiz at the beginning which asked for specific information relating to the virtual patient's anesthetic record as shown in GrabAnestheticRecord (OB1), such as a check for any regular medication or respiratory problems which may have been noted on the record. These questions were added to investigate the effect of room-scale virtual reality on trainee recall. An overview of both patients' information is shown in Figure 4.6.

		Scenario	
		Patient 1	*Patient 2*
Anesthetic Record Questions	*What was the patient's name?*	Cathy Howen	Sara Branh
	What did the patient look like? (a selection of four pictures)	2	4
	Did the patient have an allergy? If so, to what?	Wheat, soy	No allergies
	Did the patient take any regular medications? If so, what medication?	Cromolyn	No regular medications
	Did the patient have any respiratory problems? If so, what was the problem?	No respiratory problems	Sara Branh

Figure 4.6: Patient information as detailed on the virtual anesthetic record.

Game play metric data was collected by the software in the form of recorded timestamps for the completion times of each objective and distance measurements between the ideal (highlighted orange) and actual epidural kit and drug vial positions on the preparation tray within the virtual environment. For example, when the participant placed the epidural kit onto the preparation tray, the distance between the placed tray and the ideal position was calculated. Object rotation was not taken into consideration as the ideal position monochrome highlight indicates no preferred rotation.

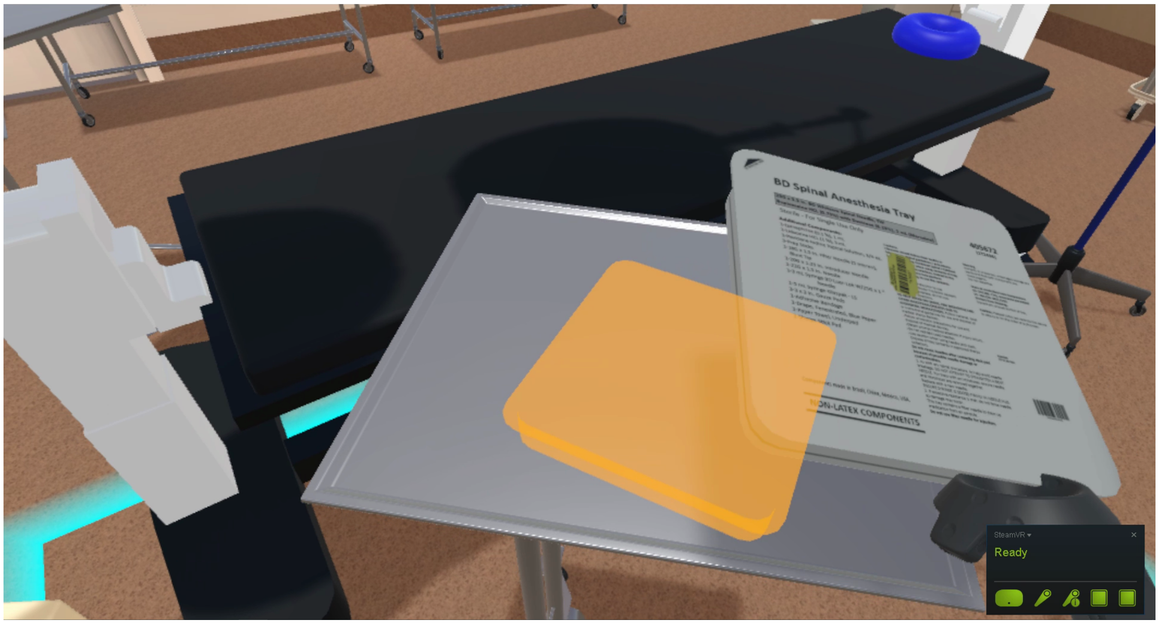


Figure 4.7: In-game view of the orange ideal placement indicator on the preparation tray. The trainee is about to place the epidural kit (lower right) onto the tray.

4.8 Results

The following section details the results for the feedback questionnaire and its subsequent sections, the collected game metrics, and ends with a discussion regarding the open-ended questions. All measures that have satisfied parametric assumptions through a Shapiro-Wilk test, have been evaluated using a paired samples t-test, while those that violate parametric assumptions have been evaluated using a Wilcoxon signed ranks test.

4.8.1 Questionnaire for User Interface Satisfaction (QUIS)

Each category of QUIS (i.e.(i) overall reactions to the system, (ii) screen, (iii) terminology and system information, (iv) learning, and (v) system capabilities) has been separated and the mean results for each across both seated and room-scale VR are detailed in Figures 4.8-4.12.

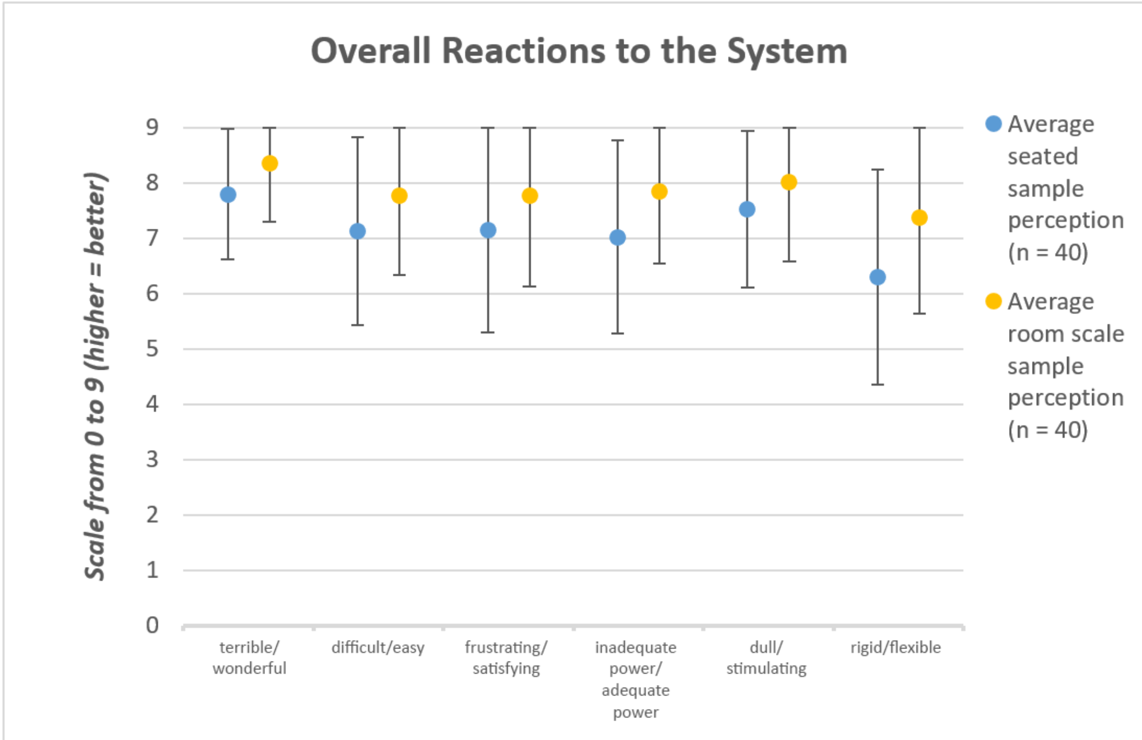


Figure 4.8: QUIS mean results: Overall Reactions to the System showing standard deviation.

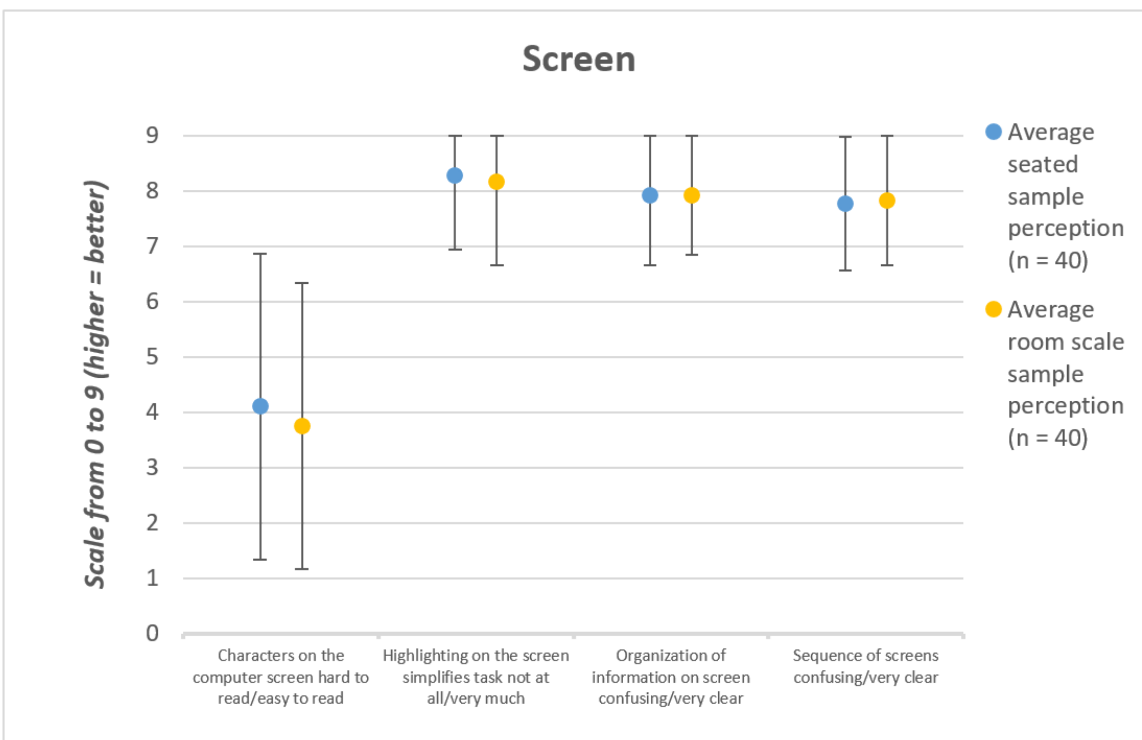


Figure 4.9: QUIS mean results: Screen showing standard deviation.

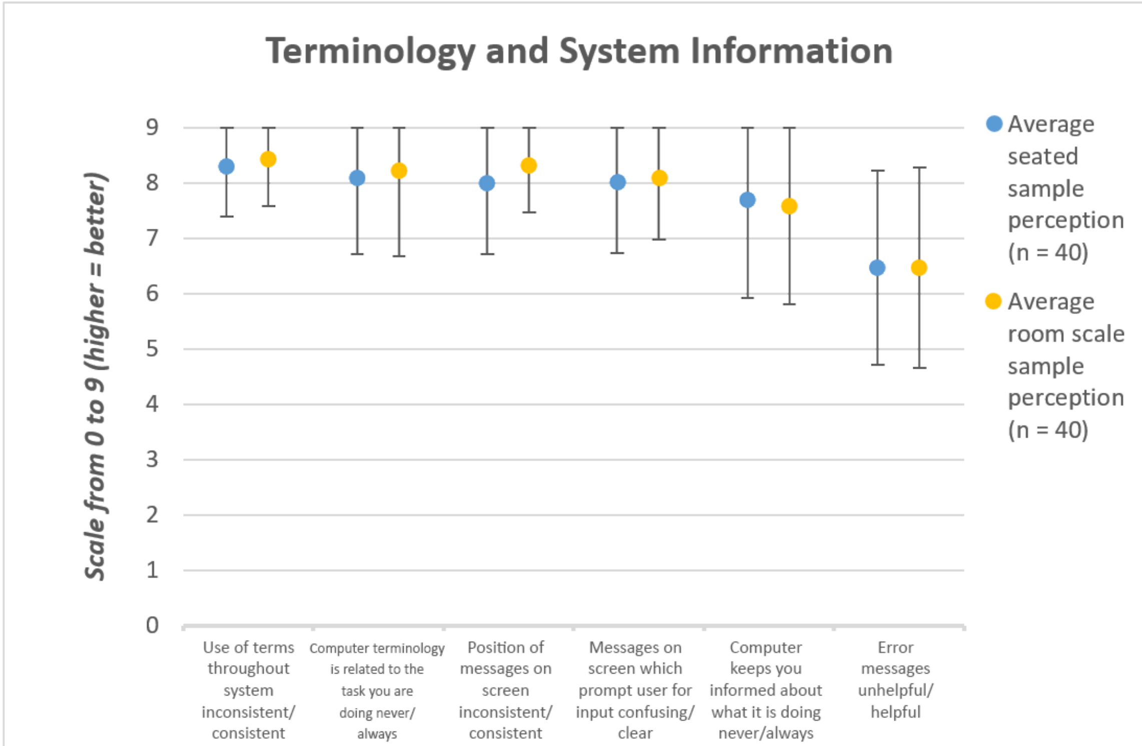


Figure 4.10: QUIS mean results: Terminology and System Information showing standard deviation.

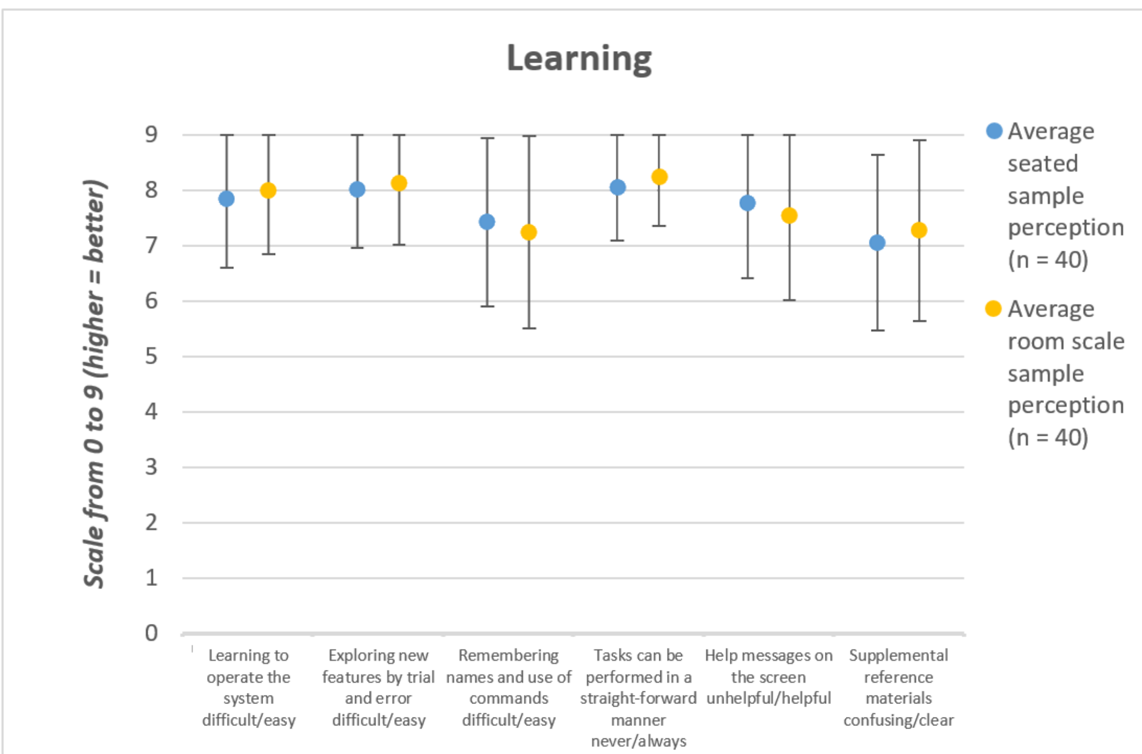


Figure 4.11: QUIS mean results: Learning showing standard deviation.

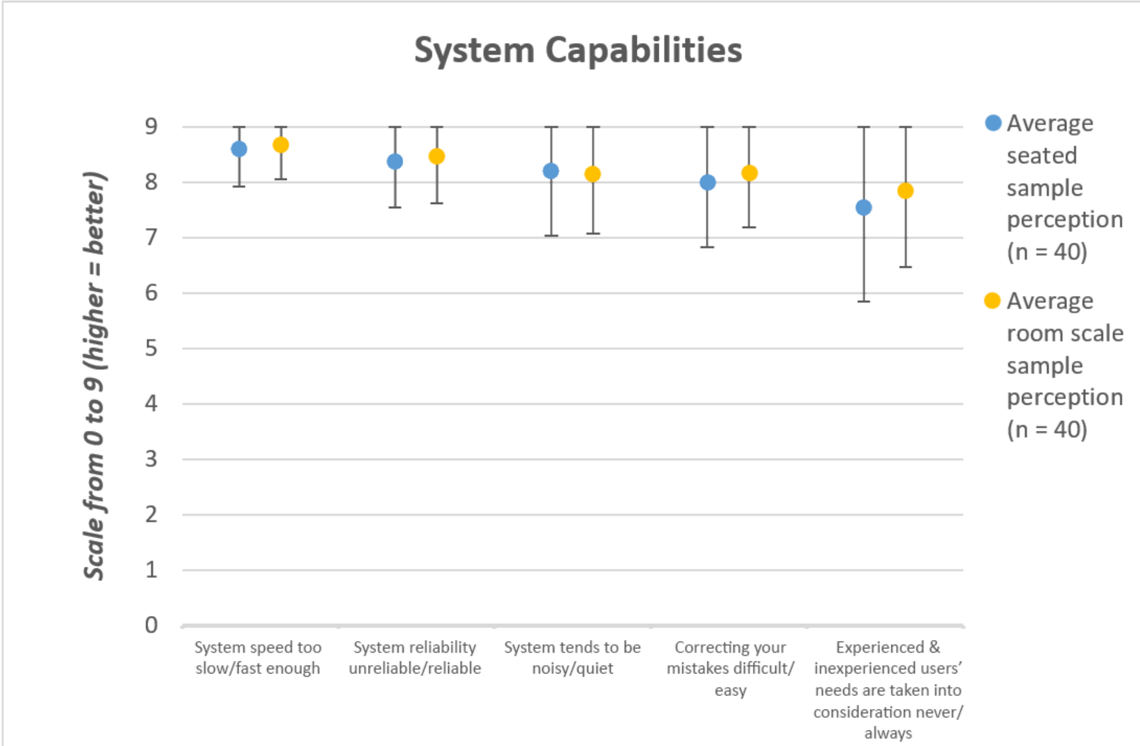


Figure 4.12: QUIS mean results: System Capabilities showing standard deviation.

The only category which indicated significance was the increased ratings in the Overall Reactions to the System category (see Table 4.2).

		Z^a	t^a	p
QUIS Category	Overall Reactions to the System	-3.806^b		<0.005
	Screen		0.843	0.405
	Terminology and System Information	-0.681^b		0.496
	Learning	-0.428^b		0.669
	System Capabilities	-1.484^b		0.138

a. Where appropriate.
b. Based on negative ranks.

Table 4.2: QUIS significance results.

The largest increase in the overall reactions category was an increased feeling of flexibility within the room-scale setup ($\text{Mean}_{\textbf{seated}} = 6.3$, $\text{Mean}_{\textbf{room-scale}} = 7.37$), with increased ratings on every other metric (Figure 4.8). This includes a larger sense of satisfaction ($\text{Mean}_{\textbf{seated}} = 7.15$, $\text{Mean}_{\textbf{room-scale}} = 7.775$) and a higher sense of adequate power on the part of the participant ($\text{Mean}_{\textbf{seated}} = 7.025$, $\text{Mean}_{\textbf{room-scale}}$

= 7.85) (Figure 4.8). The lowest rating throughout the entire QUIS was a feeling of characters on the screen being hard to read, with this sentiment growing worse from a seated to room-scale setup ($\text{Mean}_{\textbf{seated}}$ = 4.1, $\text{Mean}_{\textbf{room-scale}}$ = 3.75) (Figure 4.9). Terminology and system information was rated slightly higher during the room-scale setup ($\text{Mean}_{\textbf{seated}}$ = 7.76, $\text{Mean}_{\textbf{room-scale}}$ = 7.85) while ease of learning the system stayed quite consistent across conditions ($\text{Mean}_{\textbf{seated}}$ = 7.70, $\text{Mean}_{\textbf{room-scale}}$ = 7.74) (Figures 4.10-4.11). System capabilities were likewise rated similarly, although participants reported an increased sense of the system's capability to take the needs of both experienced and inexperienced users into consideration during the room-scale setup ($\text{Mean}_{\textbf{seated}}$ = 7.55, $\text{Mean}_{\textbf{room-scale}}$ = 7.85) (Figure 4.12).

In the scope of evaluating the game itself, the QUIS results returned high ratings across every category with the notable exception of the screen. As previously mentioned, characters on the computer screen were described as harder to read than necessary, a challenge due to the limitation in the HMD's screen resolution. This problem is discussed further in Section 4.8.6 and a possible workaround has been proposed and implemented in Section 4.9. Although error messages received the lowest rating in the terminology and system information section (6.475), this may be due to the absence of error messages within the game altogether (Figure 4.10). Despite these issues, ratings across the other categories were consistently high (>7.0) with the highest sentiments being felt in respect to the system's capabilities (>8.1) (Figure 4.12). This includes a feeling of the system being reliable (>8.3) with an ease in correcting user mistakes (>8.0) (Figure 4.12).

4.8.2 System Usability Scale (SUS)

Despite higher overall scores within the room-scale setup ($\text{Mean}_{\textbf{seated}}$ = 82.81, $\text{SD}_{\textbf{seated}}$ = 12.14; $\text{Mean}_{\textbf{room-scale}}$ = 85.44, $\text{SD}_{\textbf{room-scale}}$ = 10.62), the difference in SUS scores were not significantly different across conditions (Z = -1.768, p = 0.077). However, the high mean ratings indicate a willingness to use the system frequently. Participants rated the game as easy to use, not unnecessarily complex or cumbersome to use, and having a feeling of confidence while using the system.

4.8.3 Game Engagement Questionnaire (GEQ)

Summarized results of the different GEQ categories (i.e. (i) immersion, (ii) presence, (iii) flow, and (iv) absorption) are detailed in Figures 4.13-4.18.

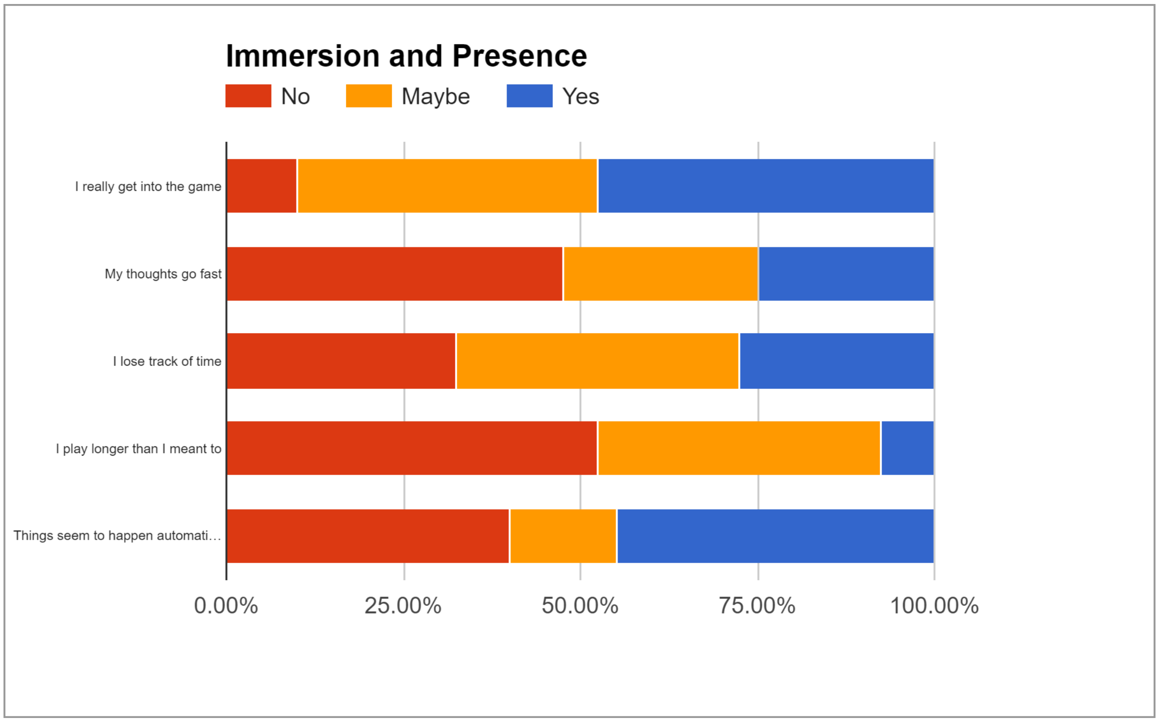


Figure 4.13: Seated GEQ results: Immersion and Presence.

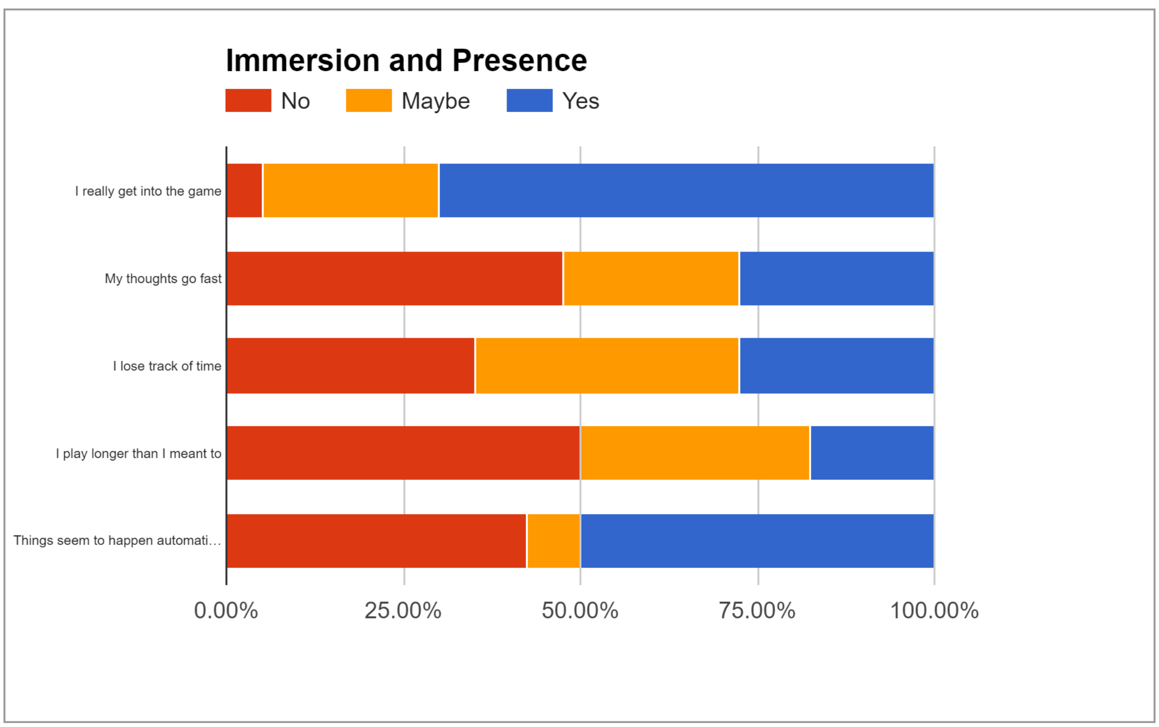


Figure 4.14: Room Scale GEQ results: Immersion and Presence.

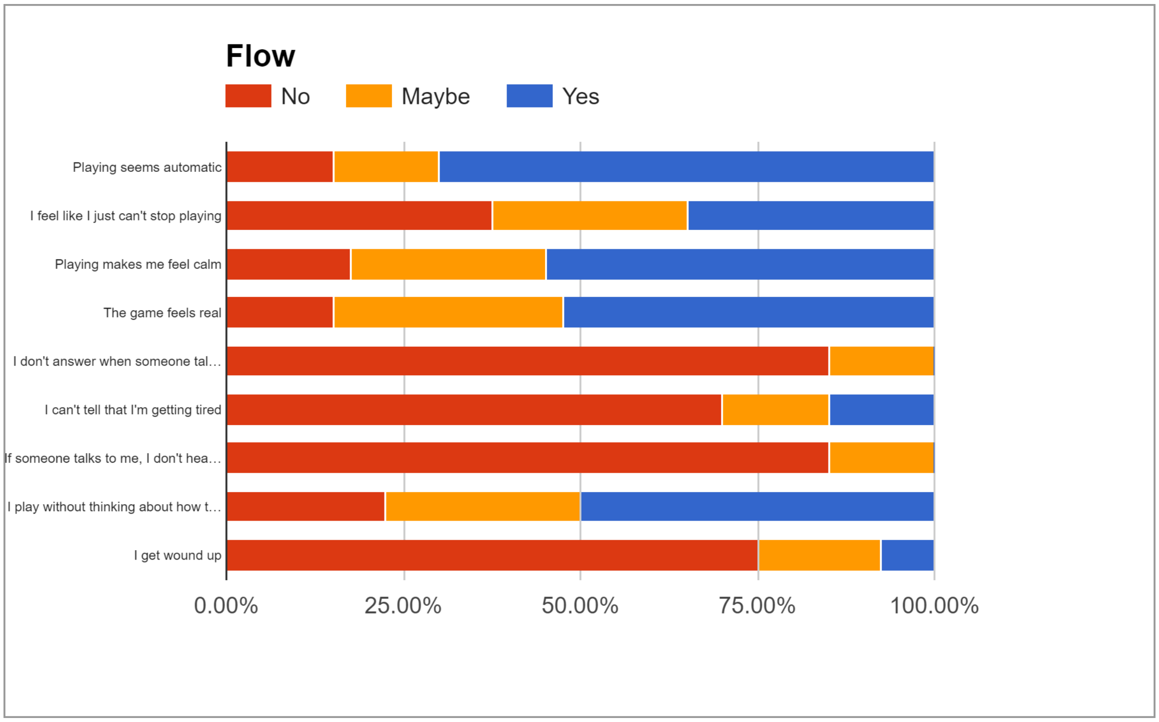


Figure 4.15: Seated GEQ results: Flow.

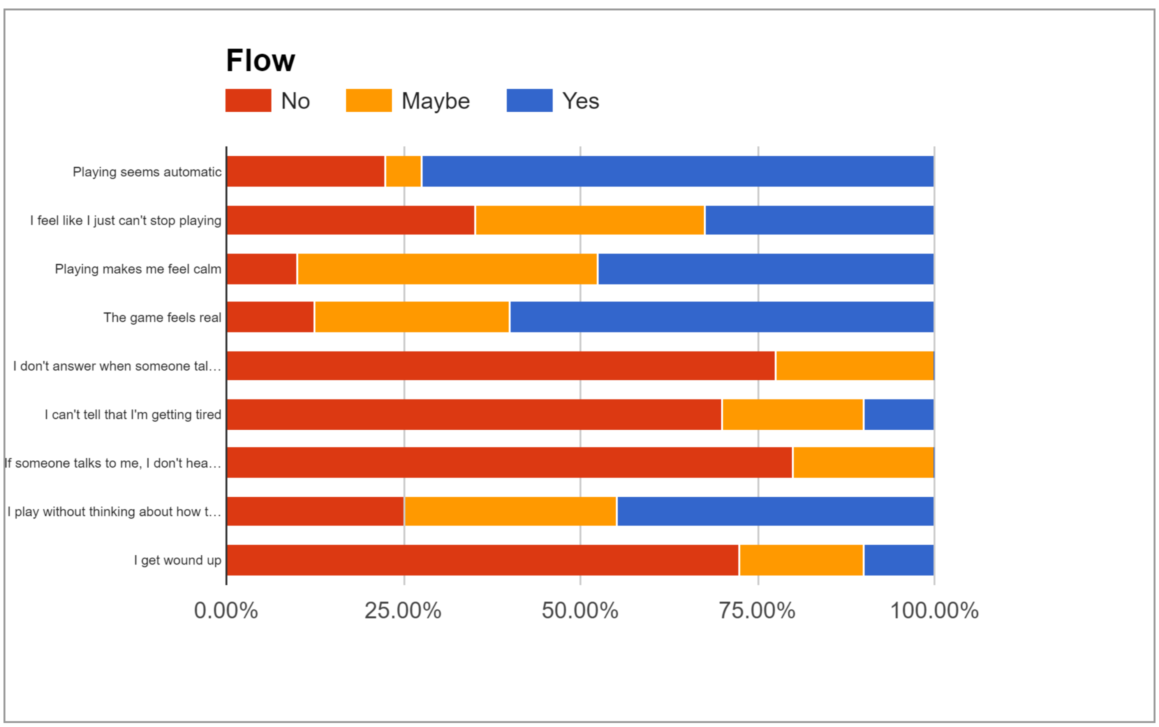


Figure 4.16: Room Scale GEQ results: Flow.

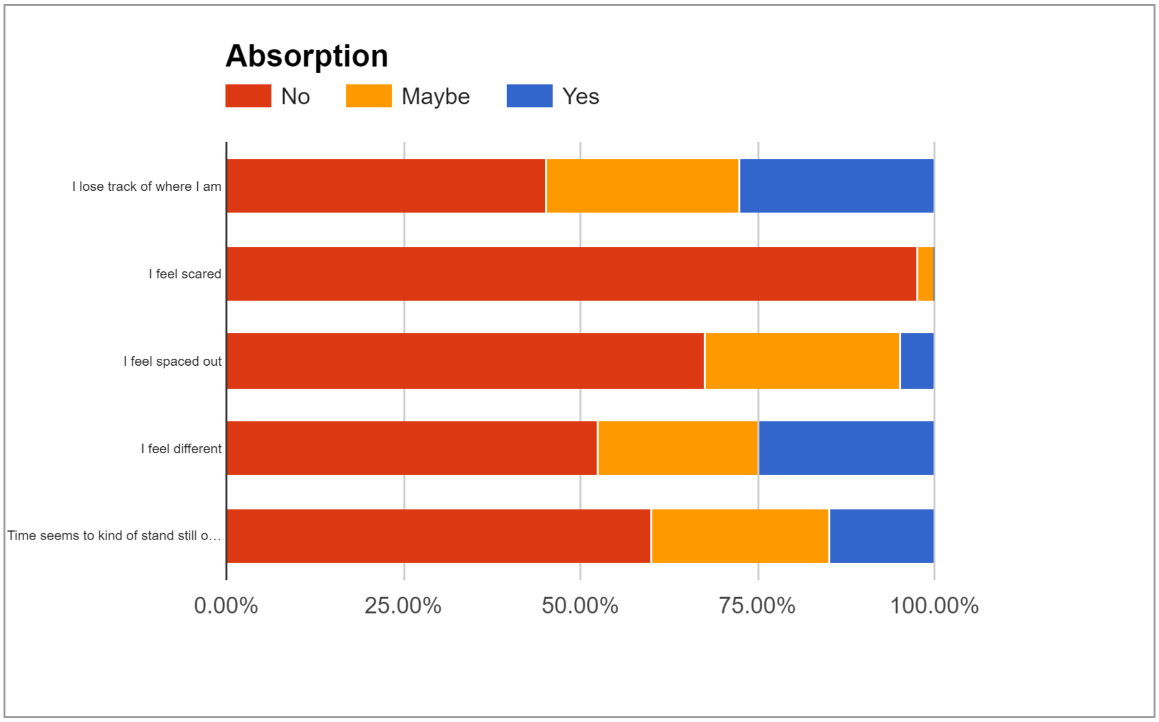


Figure 4.17: Seated GEQ results: Absorption.

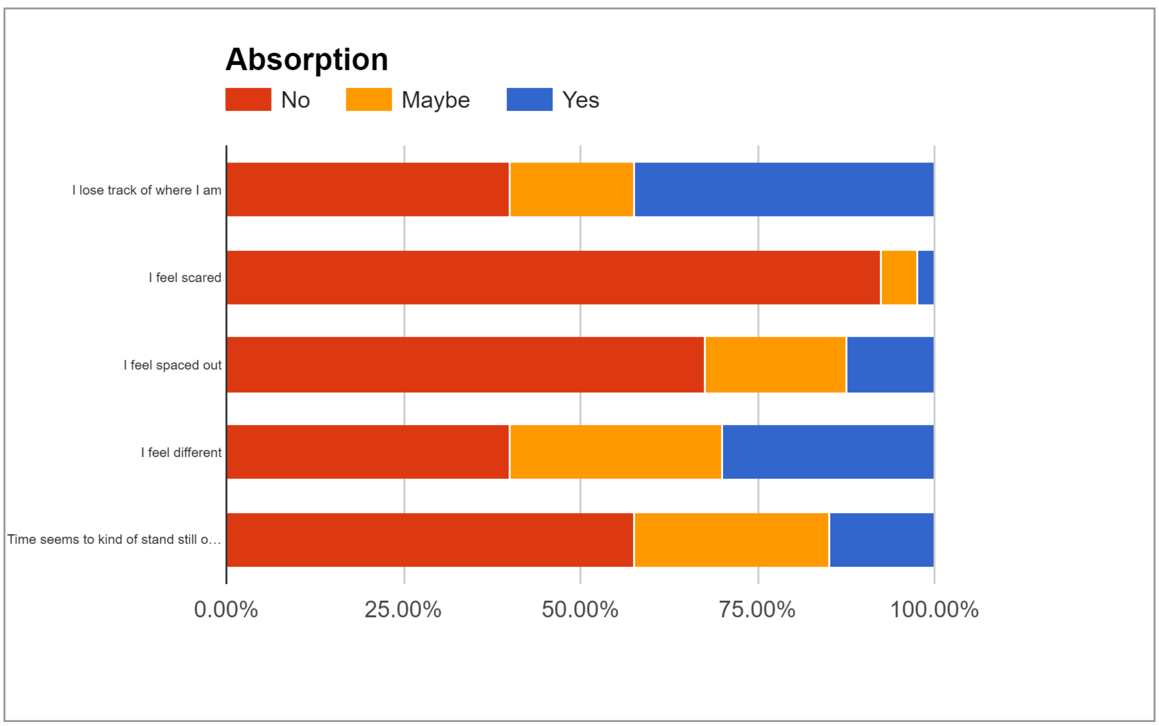


Figure 4.18: Room Scale GEQ results: Absorption.

For the purposes of statistical analysis, the GEQ was scored by assigning each possible response a numerical value: (i) No = -1, (ii) Maybe = 0, and (iii) Yes = 1. Therefore, higher GEQ scores indicate higher engagement and lower scores indicate lower engagement. Mean scores across each category of the GEQ were consistently higher during the room-scale setup compared to the seated setup, though only the Immersion category found significance. Table 4.3 provides a detailed breakdown of each category.

		Z^a	t^a	p
GEQ Category	Immersion	-2.392^b		0.017
	Presence	-0.430^b		0.667
	Flow		-0.255	0.800
	Absorption	-1.750^b		0.080

a. Where appropriate.
b. Based on negative ranks.

Table 4.3: GEQ significance results.

Accordingly, mean Immersion scores rose significantly during the room-scale setup ($\text{Mean}_{\textbf{seated}}$ = -2.5, $\text{Mean}_{\textbf{room-scale}}$ = -1.95) (Figures 4.13-4.14). During the room-scale setup, 28 participants reported 'getting really into the game' as opposed to less than half overall during the seated setup (19), and four more participants felt that they played the game longer than they meant to (Figures 4.13-4.14). In terms of flow, fewer participants reported feeling calm during the room-scale setup (19) as opposed to the seated setup (22), but opinions towards the game feeling real increased during the room-scale setup (21 seated, 24 room-scale) (Figures 4.15-4.16). Absorption was similarly affected, with six more participants loosing track of where they were (11 seated, 17 room-scale) and three more feeling spaced out (2 seated, 5 room-scale) during the room-scale setup (Figures 4.17-4.18). Interestingly, while no participant reported feeling scared during the seated setup, one did during the room-scale setup (Figures 4.17-4.18).

With respect to the game, these results indicate a good base with need for improvement. Similarly to the ACLS game, lower levels of engagement seem easier to endorse as opposed to the higher successive levels (see Section 3.7.3), as immersion scored much higher overall (>0.3) than presence (<-0.5), flow (<-1.2), and absorption (<-1.9). The game created a sense of things happening automatically for approximately half of participants, with approximately 10% being unsure. Closely tied with this, a large percentage of participants felt that play seemed automatic to them (>70%) with only approximately 17% in disagreement. Despite these positive results, room for improvement remains. Greater than 70% of the participants did not report a feeling of their 'thoughts going fast', and more than 80% did not play longer than they meant to. No participant felt that they would be unable to answer when spoken to during game play, and only 7.5% felt wound up after play. Absorption was the lowest scoring, with only 5% of participants feeling spaced out and 15% reporting time standing still during game play.

4.8.4 Anesthetic Record Quiz

The questionnaire also included five questions relating to the virtual patient's anesthetic record as presented during game play. While mean scores were slightly higher during the room-scale setup ($Mean_{\textbf{seated}} = 4$, $SD_{\textbf{seated}} = 1.06$, $Mean_{\textbf{room-scale}} = 4.15$, $SD_{\textbf{room-scale}} = 1.10$), this did not lead to statistical significance ($Z = -0.810$, $p = 0.418$). Following these results, it does not appear that a difference in VR setup leads to a significant difference (positive or negative) in trainee recall within the simulation. Part of this may be attributed to the type and amount of information presented, the method by which it is presented, and the poor readability of the anesthetic record within the HTC Vive. The issue of poor readability is expanded upon in Section 4.8.6, and future work to investigate these possible causes is discussed in Section 4.11.

4.8.5 Game Metrics

Collected game metrics offer an insight into whether the change in VR setup affected task completion time or distance estimation within the stereoscopic 3D virtual environment. In addition, these metrics help explain any areas of difficulty that participants experienced during game play. For the majority of objectives, task completion time was reduced within the room-scale VR setup (Figure 4.19). However, total game play time rose during room-scale play as opposed to seated play ($Mean_{\textbf{seated}} = 175.96$ s, $Mean_{\textbf{room-scale}} = 177.12$ s), perhaps indicating that participants took more time to explore the environment within the room-scale VR setup.

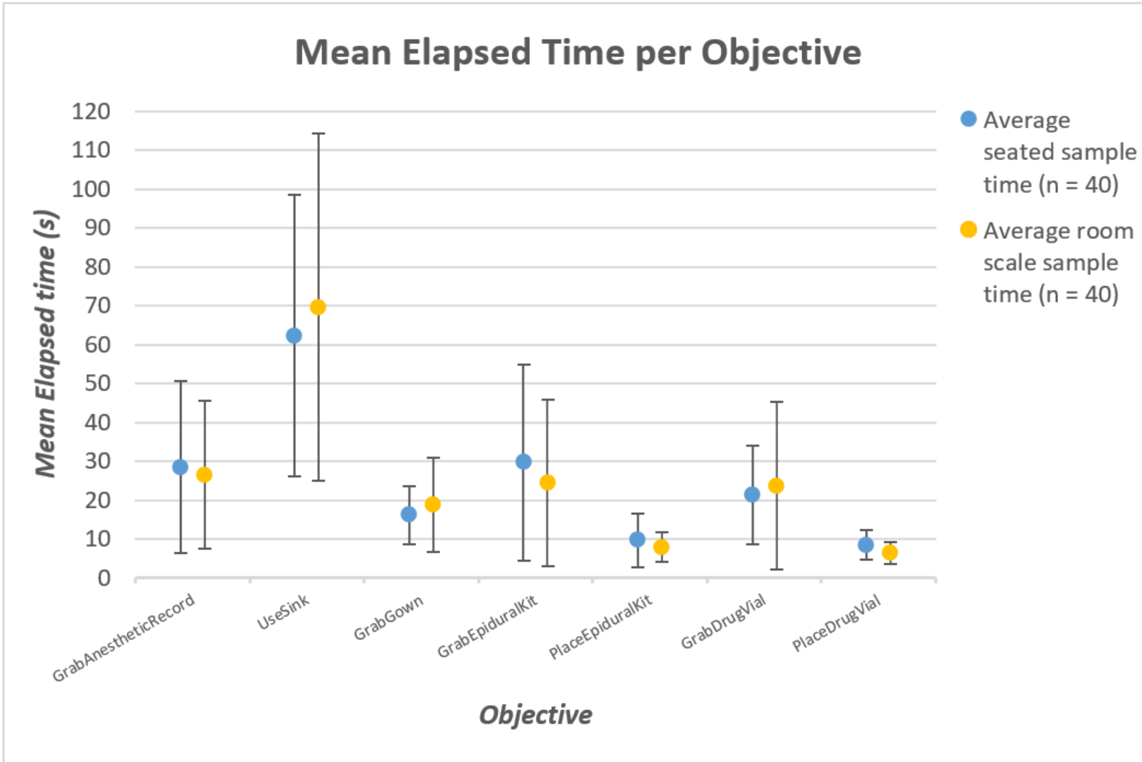


Figure 4.19: Mean elapsed time taken per objective showing standard deviation.

The only two objectives which reported statistical significance were PlaceEpiduralKit (OB5) and PlaceDrugVial (OB7) (see Table 4.4). Interestingly, these are the only two objectives in which the actions of holding an object and teleporting within the virtual environment are both done concurrently. For example, every other objective requires the trainee to teleport close to their target destination, however the action of holding an object while moving is unique to these tasks. This may indicate a correlation between trainee multitasking and performance, as occupying both their ability to hold an object and move within the environment simultaneously appears to be the most affected by the change in the VR setup. Furthermore, these are the only two objectives in which the trainee is told to place a held item onto a specific place within the environment. Trainees may obtain and hold the anesthetic record also, but there is no in-game indicator showing the trainee where to return the record to when they are finished reading it. These results may indicate that while trainee performance is less affected by being seated while doing these two tasks discretely, their combination is either hindered by being seated or afforded by having a free range of movement during a room-scale VR setup.

		Z	p
Objective	GrabAnestheticRecord	-0.282[a]	0.778
	UseSink	-0.766[b]	0.444
	GrabGown	-1.035[b]	0.301
	GrabEpiduralKit	-1.035[a]	0.301
	PlaceEpiduralKit	-2.231[a]	0.026
	GrabDrugVial	-0.121[b]	0.904
	PlaceDrugVial	-2.769[a]	0.006

a. Based on positive ranks.
b. Based on negative ranks.

Table 4.4: Objective times significance results.

One particular area of note is the drastic increase in completion time during the UseSink (OB2) objective. As this objective begins, the traineeyer has just obtained the anesthetic record and is about to read it. This inflation time would primarily be attributable to this time spent reading, including the difficulty trainees had in reading the anesthetic record whatsoever (see the results of the QUIS Screen section, Figure 4.9), increasing this time also. This time increase may also be due to the layout of the room as there is a wall blocking the line of sight between the trainee's position from obtaining the anesthetic record (OB1) and the sink in the corner (see Figure 4.1).

Object placement distance was also recorded between the epidural kit and drug vial's actual and ideal positions on the preparation tray. Room-scale VR had a large effect here, with both the epidural kit and drug vial's distances to their target position being over 60% closer than during their seated counterparts (Figure 4.20).

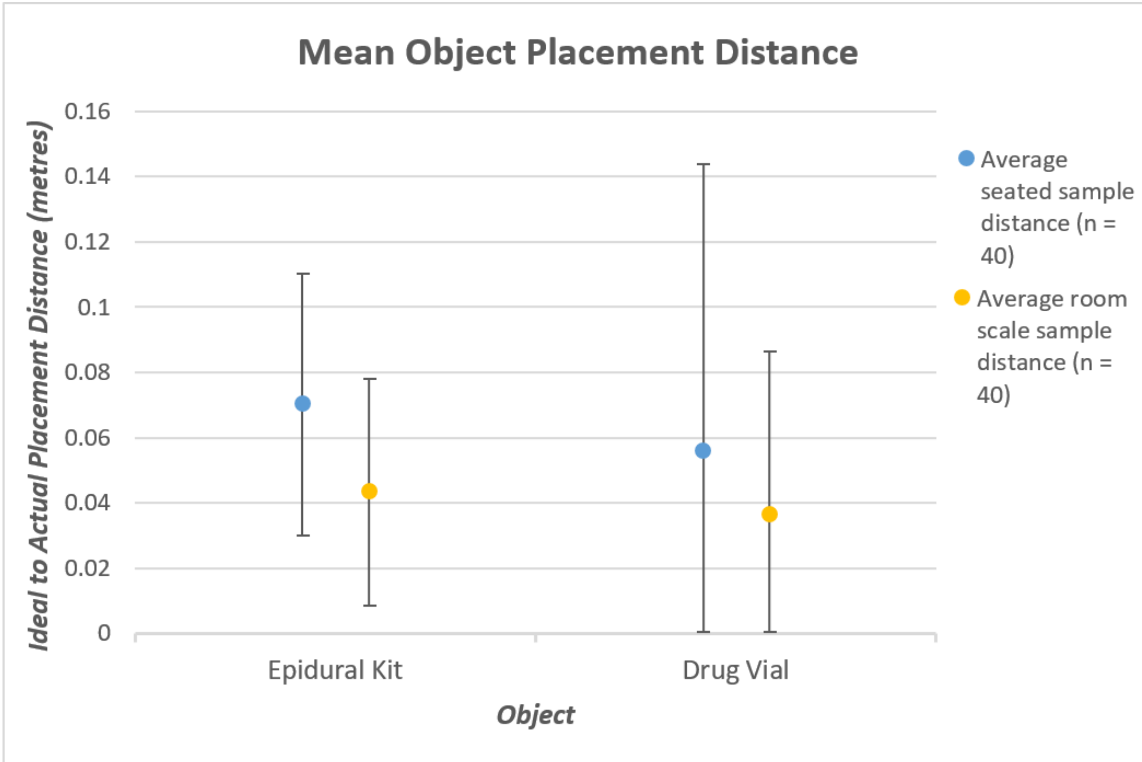


Figure 4.20: Mean object placement distance showing standard deviation.

The difference for the epidural kit was found to be significant ($p < 0.01$) while the drug vial was not (Table 4.5). This may be due to the size difference between the epidural kit and the drug vial. The epidural kit is significantly larger than the drug vial (six times as wide) and therefore feels larger in the participant's hand. The ideal placement indicator is likewise larger on the preparation tray, so the participant may feel a greater sense of control and precision when placing the epidural kit as opposed to the much smaller drug vial ideal placement indicator.

	Seated Distance (m)	Room-scale Distance (m)	Z	p
Epidural Kit	0.0702	0.0434	-2.769[a]	0.006
Drug Vial	0.0560	0.0365	-1.237[a]	0.216

a. Based on positive ranks.

Table 4.5: Object distance significance results.

The significance of increased precision within a room-scale VR setup as opposed to a seated setup may be due to several factors, among them: i) the greater degree of freedom of movement for the participant, and ii) an increased sense of immersion within the virtual environment (see Section 4.8.3). Being seated limits the trainee's natural ability to bend low, stand on their toes to obtain a taller view, and naturally turn around without having to rotate an adjustable chair. Combined with an increased sense of immersion and ease within the virtual environment, this may lead to a more natural sense of ability, particularly when performing hand manipulated precision-based tasks such as object placement.

4.8.6 Open-Ended Questions

Detailed in this section are common responses to the open-ended feedback questions at the end of the questionnaire. Many of these responses expand upon the problems revealed in the responses to the QUIS, SUS, GEQ, and game play metrics, yet also offer insight into what aspects of the game are working well and should be kept.

Overall, the majority of participants responded favorably when asked their opinions about the game during the room-scale setup as opposed to the seated setup. When asked if any of their actions or capabilities made them feel powerful or in control, 31 participants (77.5%) commented something positive after the seated setup while 35 (87.5%) commented positively after the room-scale setup. Similarly, when asked if participants ever felt limited in their capability to interact with the game in any way, five (12.5%) explicitly stated 'no' after the seated setup yet 15 (37.5%) stated 'no' after the room-scale setup. Finally, the seated setup received two (5%) explicit 'no' responses when asked if any part of the game felt unnatural or unintuitive, while nine (22.5%) responded 'no' after the room-scale setup. In general, these results seem to indicate a more positive overall trainee experience when utilizing room-scale VR as opposed to seated VR.

20 participants (50%) mentioned their ability to walk around during the room-scale setup as feeling either natural, intuitive, or empowering.

> *"The addition of walking made me feel more immersed and therefore more powerful as a character in the game."*
>
> *-Participant 8 (20th October, 2016)*

> *"Moving around within my own operating space without teleporting [felt empowering]. Once teleported however, I would feel powerful within that operating space."*
>
> *-Participant 31 (1st November, 2016)*

After the seated VR setup, 18 participants (45%) mentioned staying in a chair without lateral movement as limiting, unnatural, or unintuitive. Interestingly, two participants described their game play while seated as feeling like they were bound in a wheelchair. This raises the point that utilizing VR in creative ways may offer trainees an increasingly immersive and engaging insight into cultural, societal, or physical disability issues which they otherwise wouldn't be able to experience.

> *"In a weird way I almost feel like I sort of understand a little bit what it might be like to be in a wheelchair."*
>
> *-Participant 5 (19th October, 2016)*

> *"Being bound to a chair felt unnatural. I felt myself "teleporting" much more than when I was able to freely walk around."*
>
> *-Participant 13 (24th October, 2016)*

The most frequently mentioned aspect of the game which was described as empowering, natural, or intuitive was object manipulation and interaction through the hand controllers. 28 participants (70%) mentioned reaching into the virtual world and grabbing or holding objects as a positive feeling, with four explicitly mentioning the effect of gravity on objects (either thrown or dropped) as meaningful.

> *"Being able to pick important items up and move them around in space relative to my actual body made me feel rather powerful in that I have this control over the game world."*
>
> *-Participant 1 (18th October, 2016)*

> *"I dropped the patient record and had to kneel down to pick it up again. I thought this was a really nice touch that I found that I didn't expect but was really happy that the interaction worked. It legitimized the experience for me and from that moment I was far more immersed."*
>
> *-Participant 5 (19th October, 2016)*

The positive or negative sentiment with respect to the teleportation ability was mixed. While eight participants (20%) mentioned teleportation favorably, 13 (32.5%) described the ability as unnatural or unintuitive. Some of the negative remarks indicated that since teleportation is not possible in the real world, the participants' suspension of disbelief into the game was hindered. Despite this, teleportation might be the best possible movement mechanic over larger distances in VR currently.

"The teleportation was nifty. It made it easier to move around the room."

-Participant 26 (28th October, 2016)

"The movement was a little unnatural but I think it's probably the best way to move over moderate to large distances in VR with now. Probably just takes some getting used to."

-Participant 5 (19th October, 2016)

"The teleportation part was the only part unnatural in general, just because it is not physically possible."

-Participant 38 (3rd November, 2016)

The technical ability of the HTC Vive to accurately track the trainee's headset and hand controllers were also mentioned by four participants (10%) as facilitating natural interactions within the game. Some were so impressed by the precision of the hand controllers that they expected to be performing more fine-tuned tasks.

"My arm and head movement felt natural in the space."

-Participant 1 (18th October, 2016)

"I think it [the game] could have benefited from utilizing the precision of the Vive controllers more effectively. For example, having to perform some sort of medical task on a patient."

-Participant 16 (25th October, 2016)

The HTC Vive hand controllers and specific controls of the game were mentioned positively by some participants, although three participants (7.5%) suggested making all controls ambidextrous instead of just the object grabbing interaction possible on either of the trigger buttons. Currently, teleporting and viewing the objectives list is exclusive to the left hand, which created an unnecessary learning curve that could have been avoided.

"The location of the buttons on the controllers and their functions within the game felt intuitive."

-Participant 30 (31st October, 2016)

"Considering there is a lack of input required for the game, make it so that both the left and right controller can cast the pointer instead of just the left controller. Often times I would choose to hold something in my left hand and do other things with my right."

-Participant 6 (19th October, 2016)

Various aspects of the game's realism either through the scenario or virtual environment were mentioned positively, which indicates that the effort spent to develop the environment to realistically match a real-world space was worthwhile. This also adds credibility to the scenario developed with the expert guidance of Dr. Alam.

"Mainly just the walking aspect and the numerous medical equipment I saw [felt natural or realistic]."

-Participant 8 (20th October, 2016)

"The setting [felt natural or realistic]. Once I had the controls figured out it was like being in a clinic just trying to get through the checklist given to me."

-Participant 31 (1st November, 2016)

Several minor game play glitches were highlighted by four participants (10%) as contributing to an unnatural feeling. These primarily dealt with either teleporting into virtual objects or being able to freely move into a virtual object once close enough.

"Missing the mark and being half inside walls."

-Participant 11 (21st October, 2016)

"The boundaries didn't seem well enforced i.e. one could easily step over to anywhere in the game and through the objects."

-Participant 21 (26th October, 2016)

Although the teleportation mechanic was limited by the grid on the floor designating valid areas to teleport to, it is true that the game didn't explicitly prevent participants from walking into virtual objects or past virtual walls. This approach was taken to avoid the worse alternative of artificially stopping trainee movement when entering restricted areas, which would immediately create a sense of disconnect between the trainee of the VR system and their virtual representation within the game world. As accurate tracking of 3D position and rotation of the user's head is paramount to VR engagement, any efforts to diminish this will typically only yield negative results.

Despite this limitation of the system, some participants (six, 15%) were aware of the HTC Vive's other limitations with respect to the physical play space or connecting wire between the headset and the computer. Only one participant (2.5%) noticed these limitations during seated play, while the other five realized these limitations during the room-scale play due to the increased nature of interaction afforded by physically moving around within the play space. While room-scale VR may provide several important benefits, it appears that participants were increasingly aware of the system's limitations as opposed to seated VR.

> *"It felt strange moving within the system in that it was weird to have to be aware of both the virtual and physical environment you're in, while only being able to see the virtual environment."*
>
> *-Participant 30 (31st October, 2016)*

> *"I was concerned about the location of the connecting wire and becoming tangled."*
>
> *-Participant 39 (4th November, 2016)*

The second most frequently cited issue which contributed to a feeling of limitation or a sense of the system being unnatural or unintuitive can be categorized as software simplifications put in place by the developer to increase system performance while in demanding 3D VR. Mentioned by 12 participants (30%), these include the simplification of collision hulls on virtual objects, the absence of a trainee virtual avatar, and limiting which objects are interact-able with the hand controllers.

> *"I was not able to direct the teleportation ray through objects that I was able to see through."*
>
> *-Participant 6 (19th October, 2016)*

> *"I didn't like... that I didn't seem to have a body."*
>
> *-Participant 14 (24th October, 2016)*

"I want to be able to make mistakes by picking up the wrong items... so that I can see what the implication would be and thus would be less likely to make those mistakes in a real-world scenario. I want to actually put on the gloves and not just tap the box and the action is magically done. This would make players feel more engaged and add to the realism of the environment."

-Participant 20 (26th October, 2016)

The inclusion of a virtual trainee avatar will require significant development time in 3D modeling, rigging, and texturing the avatar, and game implementation and reverse kinematics will be needed to create a convincing sense of realistic hands and arms. Multi-million dollar budget VR video games have largely avoided attempting this implementation and frequently show only a pair of disembodied hands as representations of the HTC Vive hand controllers. For example, Rocksteady Studios released Batman: Arkham VR for the PlayStation VR on October 11th, 2016 [82]. Throughout the game, the player's avatar (Bruce Wayne/Batman) is represented only by a pair of disembodied hands. However in one sequence, a mirror appears in front of the player avatar and shows the full Batman character accurately following the movements of the player's hand controllers (Figure 4.21).

Figure 4.21: In-game first-person view of Batman: Arkham VR. The player's disembodied hands are in the foreground while a mirror in the background shows the full Batman player avatar [81].

Although the development team could afford to create the 3D avatar, they neglected to have it represented in the player's position (i.e. looking down would show the avatar's arms, chest and legs). Due to the trainee's body and elbows not being tracked in 3D space, it is impossible for the system to know exactly where they are and therefore represent them accurately within the game. This disconnect between the trainee's actual body (especially the arms) and avatar's virtual body would be disconnecting and possibly break the trainee's immersion, and is therefore avoided. Until accurate, full-body motion tracking is available in conjunction with VR, developers should instead focus their efforts elsewhere.

The other issues of loose object collision hulls within the epidural preparation game and the lack of interact-able objects are discussed further and iterated upon in Section 4.9.

The most severe issue participants mentioned was the poor readability of the anesthetic record text. 11 participants (27.5%) described the text as blurry or unreadable, with some going so far as to say that the anesthetic record was 'impossible' or 'incredibly difficult' to read. Two participants included suggestions for possible solutions.

"I think the only big issue was the text, I wouldn't say it was necessarily too small because it was scaled appropriately to what a paper form would look like but I had a hard time making out fine details. Maybe some kind of magnifier or enlarging the paper while it is held?"

-Participant 5 (19th October, 2016)

"Text on the patient doc and the note pad get hard to read. Would be great if you can pull them apart to resize them like on a phone."

-Participant 7 (20th October, 2016)

As Participant 5 notes, the anesthetic record size was scaled appropriately to a real-world sheet of paper, and the record itself is a scanned copy of a real-world anesthetic record form from the Sunnybrook Health Sciences Centre in Toronto, Canada. The difficulty in readability may be a limitation of the HTC Vive HMD's display resolution, though the idea of a magnifier is discussed and implemented in Section 4.9.

Finally, as an overview of participant reaction to both the epidural preparation game and the HTC Vive, two participants described their experience using the HTC Vive and playing the serious game for the first time:

"It felt very natural, without hav[ing] any previous VR experience I felt that it was very easy to jump into and play the game."

-Participant 15 (24th October, 2016)

"Very good game... easy to use and helpful for anyone that is trying to work or train to be in a clinic/hospital."

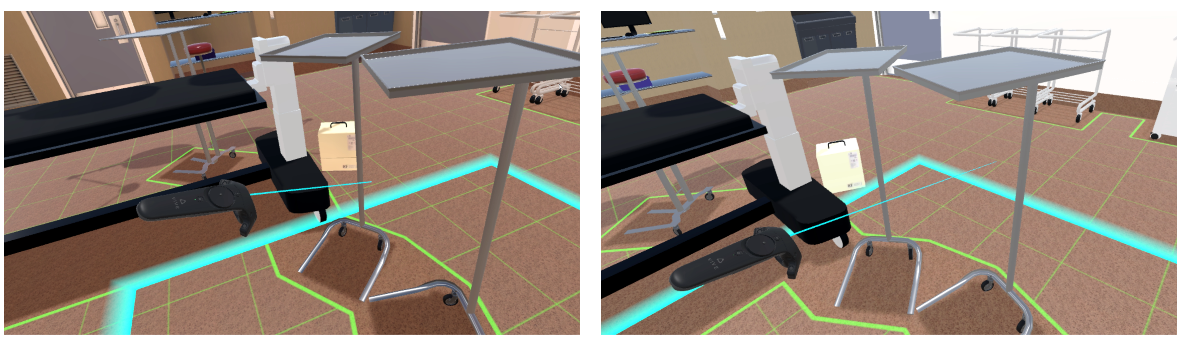
-Participant 38 (3rd November, 2016)

4.9 Iterative Development

An initial round of iterative development was conducted to remedy many of the issues discussed previously. Among these are i) allowing ambidextrous controls, ii) refining the teleportation mechanic to not collide with large objects in the environment, iii) increasing the number of interact-able items to allow for more trainee exploration, and iv) implementing a zoom function when reading the anesthetic record.

As noted by several participants (see Section 4.8.6), the restriction of certain game play actions to only one of the hand controllers introduced an unnecessary learning curve that could have been avoided. Previously, the teleportation mechanic and viewing the objectives list was exclusive to the left controller while holding items was possible with both. In this iteration of post-study development, the teleportation mechanic and objectives list have been made available on the right handed controller as well. It is anticipated that this will help facilitate trainees of all handedness and game play styles.

Software simplifications put in place by the developer were responsible for the second most frequently cited cause of a feeling of limitation by 12 participants (30%), with one issue being the interaction between the teleportation ray and some objects within the virtual environment. To greatly reduce the system processing power required to handle collisions between objects, many elements within the room are represented as simple convex collision hulls instead of more accurate mesh-based collision bodies. For example, the freestanding trays (such as the preparation tray) and patient bed have large open areas underneath them, however due to large collision hulls, the teleportation ray is not able to pass through them (Figure 4.22).



(a) The original teleportation mechanic

(b) The modified teleportation mechanic

Figure 4.22: Iteration of the teleportation mechanic ((a) pre and (b) post). The original ray is being blocked by large collision hulls underneath the empty space of the preparation stands, while the modified ray passes directly through them.

Instead of changing the collision hulls of the larger blocking objects to be more precise (which would require significantly more system processing power to maintain), the teleportation mechanic was instead changed to ignore all objects within the environment except for the valid teleportation area on the floor through a layer mask. When the teleportation ray is raycast within the game, a mask is applied to limit the types of objects onto which the raycast may collide. This has the benefit of retaining the efficient collision hulls and should also improve system performance based on the limitation on the amount of physics objects which the system has to collide against during the raycast. Clever implementation and use of system resources such as this is crucial to maintaining a low system load and therefore providing a smooth game play experience.

An additional software simplification that created issues was the reduction of the number of objects within the environment which were interact-able by the trainee's hand controllers. Each interact-able object requires physics calculations for both gravity and collisions, and it is easy to inflate the number of these objects without considering their taxing effect on system performance. However, as the most frequently cited aspect of the game which contributed to a sense of empowerment was the hand controllers (see Section 4.8.6), I have selectively allowed the most prominent objects which trainees might take interest in to be interact-able. 13 objects were modified in this way, and included the warmer on the floor beside the preparation tray, the computer mouse directly beside the anesthetic record, and various small boxes of surgical gloves placed around the room.

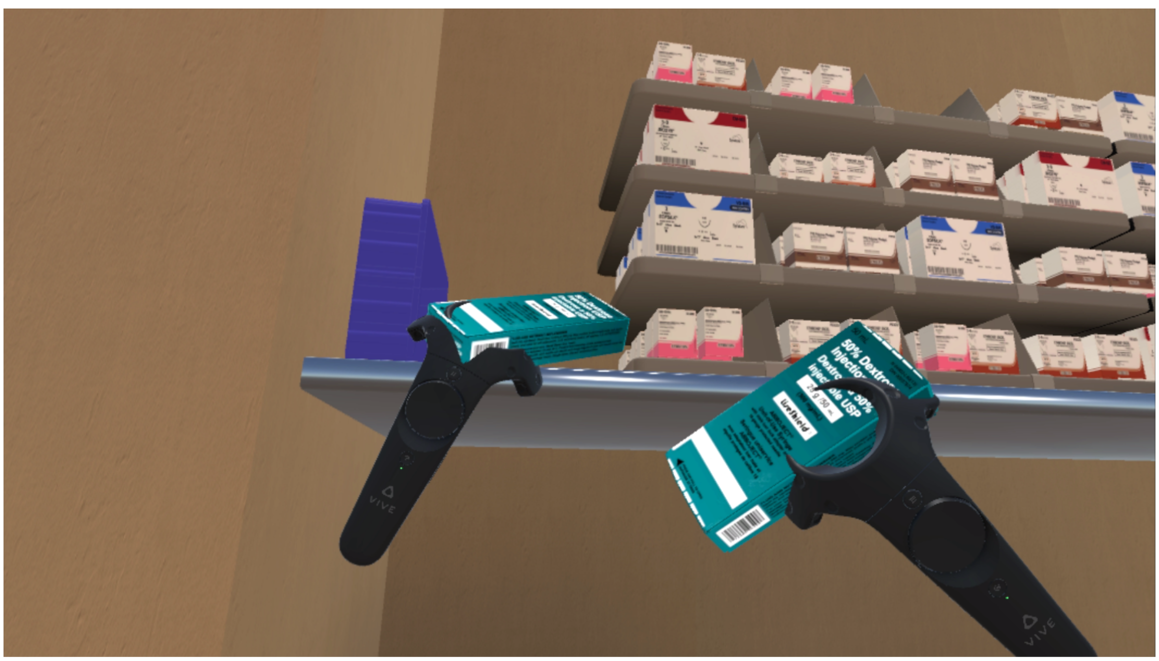


Figure 4.23: In-game first-person view of newly interact-able boxes above the computer desk. The blue container and two held dextrose boxes are interact-able, though the large shelf of small boxes are not.

It is important to note that limitations are still selectively in place. For example, there is a large shelf of small individual supply boxes above the computer desk (Figure 4.23). Setting each little box to be interactive and creating the collision hull necessary of the dividing shelving would be the use of a large amount of system resources for one small area of the room, and has been left out.

Finally, the most severe issue participants experienced was the poor readability of in-game text, notably on the patient's anesthetic record. Although the record could be physically held and brought closer to the face, this may have felt like an unnatural sensation that wouldn't be necessary in the real world. This problem highlights the conflict in attempting to achieve visual realism using modern VR devices. The anesthetic record was a scanned copy of a real-world record, so it is perhaps the most realistic it can be, though the resolution of the HTC Vive HMD's display is still insufficient for fine details, especially text. One possible solution may be to use a modified anesthetic record that has fewer and larger text elements on it, though that would reduce realism within the simulation. Like the modification of the teleportation mechanic, clever workarounds can be used to increase usability without sacrificing realism.

As Participant 5 suggested, a magnification mechanic has been added to assist text readability with regards to the anesthetic record. While holding the record, the trainee can touch a hand controller's trackpad to display a zoomed-in view in front of their hand, much the same as if they were holding a magnifying glass (Figure 4.24).

Figure 4.24: In-game first-person view of the magnification mechanic. The left hand controller is holding the anesthetic record and the right hand controller is being used to magnify what is underneath it (the large overlay circle).

To keep with the paradigm of ambidextrous controls, the magnifier is available on either controller while the other is holding the anesthetic record.

4.10 Study Discussion

Following the results of the usability study and iterative development, it is necessary to reflect on the study's hypotheses, namely:

- Minor usability issues exist within the game's interface or game play.
- The game is engaging for the participant to play.
- The game feels realistic, especially regarding the visuals.
- Room-scale VR has a positive effect on game engagement and participant performance within the three categories of memory, task completion time, and spatial distance estimation.

The game's interface contained the largest usability issue with hard to read text, though this may be primarily due to a hardware limitation of the HTC Vive's HMD (see Section 4.8.1). The game play scenario seemed clear with instructions, although the interaction between the teleportation ray and some objects within the environment may have caused a break in realism (see Section 4.9). Overall, these usability issues were not significant enough to prevent the serious game from being completed, and fixes have been attempted through iterative development.

Similar to the ACLS serious game, overall the epidural preparation serious game failed to provide participants a high sense of game engagement. Although some participants reported the effects of immersion, the higher successive levels of game engagement (presence, flow, and absorption) were more difficult to endorse (see Section 4.8.3). Some of this may be attributed to the various usability issues extensively discussed, however future work should focus on adding game mechanics designed to promote engagement.

With respect to the visuals, participants positively mentioned the virtual environment's realism with some specifically highlighting the realism of the serious game scenario (Section 4.8.6). The effort spent to replicate a real-world operating room and collaborate with a medical content expert to create a realistic scenario seems to have paid off.

Finally, room-scale VR did have a positive effect on game engagement and on some aspects of participant performance. Game engagement with respect to immersion was significantly higher, and tasks which combined active movement and object manipulation saw a completion time reduction within room-scale VR (see Section 4.8.3, Section 4.8.5). Spatial distance estimation was also improved for larger objects, although participant recall through a post-game play quiz was not significantly affected (see Section 4.8.5, Section 4.8.4).

4.11 Future Work

The epidural preparation serious game has provided great insight into the positive effects of room-scale VR as compared to seated VR, with usability testing and iterative development addressing many of the major issues noted by participants who played the game. Despite this, more focused usability could provide greater depth. For example, tracking the trainee's body movement, view direction, and hand movements throughout play could provide additional metrics useful to determine areas of common interest within the virtual environment. Though a preliminary investigation into trainee recollection ability within VR was performed through the information on the patient's anesthetic record, more validated approaches for memory ability testing could be taken. These could include specifically looking at the type of information presented or the method by which it is presented to the trainee.

The configurations of room-scale and seated VR were chosen due to the main selling-point features provided by the two most popular high-quality consumer-grade VR systems; the Oculus Rift representing seated VR experiences and the HTC Vive representing room-scale VR experiences. Although standing VR, which is VR with the user standing but not being able to physically move laterally within the real-world, has not been investigated here. Perhaps the hybrid approach of standing VR would provide some of the benefits of room-scale VR without the accompanying drawbacks, such as a necessary increased awareness of two 'worlds' (the real physical world and the virtual world).

4.12 Recommendations and Guidelines for Designers of Serious Games and Virtual Simulations utilizing VR Devices

Developers of serious games and simulations and those who wish to utilize consumer-grade VR from both a software-design and scenario-design perspective can learn a number of takeaways based on the development of this epidural preparation serious game. Below I outline five general recommendations and three guidelines that have been drawn from my personal experience as well as from the results of this initial study. The guidelines specifically have been drawn based on the data gained from the usability study.

The five general recommendations for designers of serious games and virtual simulations utilizing VR devices are:

- *Interdisciplinary Team*: As noted during the development of the ACLS serious game, the diversity of skills within an interdisciplinary team has a large positive effect on the end product. The epidural preparation serious game was a combination of knowledge and skills from the areas of software and game development, engineering, and health science education. These each had an effect on the design of the game, from the more 'gameful' elements such as the controls and interactions, to the design of the scenario itself from a medical educator perspective.

- *Allow for explorable interactions based upon motion controls*: If using motion controllers, try to provide ways in which trainees can explore and interact with their virtual environment besides the specific elements needed to progress through the serious game or simulation. Generally, game players want to push virtual buttons, flick virtual light switches, and throw around virtual objects. Neglecting to include these optional and free-flowing type of interactions may create a sense of a static, unnatural or unintuitive virtual environment.

- *Ambidextrous Controls*: If using motion controllers, provide ambidextrous controls if possible. Ambidextrous controls eliminate the need to check for trainee handedness and allow the trainee to interact with the game in the way which is most comfortable for them. This may be impossible to accomplish depending on the number of discrete buttons needed within each different serious game or simulation, though any efforts towards ambidexterity will be appreciated.

- *Strive for Realism*: As with the ACLS serious game, the visual fidelity of the virtual operating room was complimented by participants and helped to create an overall sense of system realism. The creation of these assets would not have been possible without high-quality reference materials gathered before and during development. While not currently employed in the epidural preparation serious game, the inclusion of audio cues has also proven to create a positive effect on participant immersion and subjective satisfaction of the system. Where possible, strive for realism, especially when attempting to recreate real-world locations or situations.

- *Work around system limitations*: Developing software, especially system-intensive software such as serious games or simulations, requires clever workarounds of system hardware limitations. The virtual world can never be completely realistic in its visual or auditory fidelity and physics or image-based effect calculations require significant system processing power. Work around these limitations where possible, such as only using high-resolution textures where especially needed or limiting the amount and complexity of physics calculations. While technologically impressive, modern consumer-grade VR still has its limitations, mainly the display resolution and a physical tether between the HMD and the computer. These limitations can be minimized, however, by clever use of game mechanics such as a magnification feature to overcome a low screen resolution.

Drawn directly from the data significance from the study, I propose three guidelines for designers of serious games and virtual simulations utilizing VR devices:

- *Prefer room-scale VR, if appropriate*: The effect of using room-scale VR as opposed to seated VR saw numerous positive effects. Participants felt more immersed (see Table 4.3) and felt more favorably towards the serious game in general (see Section 4.8.6), and overall system usability increased (see Table 4.2). Room-scale VR also contributed to a reduction in some specific task completion times, indicating increased participant performance (see Table 4.4). However, room-scale VR might not suit every serious game or simulation's needs. For example, seated VR may be an interesting way to discuss social or human disability issues such as those persons confined in a wheelchair.

- *Use motion controls if possible*: The HTC Vive's motion controllers were the most discussed method of being able to empower the participant and create a sense of the game feeling natural or intuitive (see Section 4.8.6). Among the major consumer-grade VR devices currently available, only the HTC Vive and PlaystationVR feature motion-tracked hand controllers of some kind. When considering which VR system to use, do not neglect the impact that properly using motion-tracked hand controllers can make.

- *Use different types of interactions together*: Although different game mechanics and interaction styles each contribute their own effects, merging these together can create benefits greater than the sum of their parts. For example, combining active movement and object manipulation produced positive effects on task completion times compared to those tasks which used one of these two mechanics at a time (see Table 4.4).

4.13 Summary

In this chapter I have discussed the development of a serious game for epidural procedure preparation with the intent to investigate the differences between seated and room-scale VR. An initial usability study was conducted with 40 participants ranging from a Game Development to Health Sciences specialization, and the results were analyzed to pinpoint current issues. A round of iterative development was undertaken based on these results, and the changes and rationale behind them was outlined.

The effects of room-scale VR compared to seated VR were discussed, most notably being an increased sense of participant immersion (see Section 4.8.3), participant sentiment towards the serious game (see Section 4.8.6), and overall system usability (see Section 4.8.1). Room-scale VR also increased participant performance through a reduction in task completion times for tasks which required the concurrent combination of trainee movement and hand controller interactions (see Section 4.8.5).

Finally, the game and usability study's outcomes were summarized in five recommendations and three guidelines for the developers of other serious games and simulations utilizing consumer-grade VR to build upon in the future.

Chapter 5

Discussion

5.1 Overview

Within this chapter I will discuss the results from both previous studies and their implications on traditional and virtual simulation, virtual reality, and serious games. The decision of which VR setup to proceed with in the ACLS serious game based on the results of Chapter 4 will be made with an explanation behind the decision included too. Possible future work with respect to these two serious games as well as to VR-based serious games in general will be proposed and the chapter concludes with a description of the total contributions of this thesis to the field of Computer Science.

5.2 The ACLS Serious Game in VR

From the beginning of the project, the ACLS serious game was meant to eventually transition into a VR implementation. However, it was unsure whether seated, standing, or room-scale VR should be used to best achieve the learning outcome of gaining ACLS skills. Due to this, development of a desktop-based version proceeded while running a separate study to address this issue was considered.

The epidural procedure preparation serious game and the resulting usability study has enabled the decision to pursue a room-scale VR implementation of the ACLS serious game. There are four results from Chapter 4 which influence this decision: i) increased overall positive reactions to the usability of the system, ii) increased trainee immersion, iii) shorter task completion times during some tasks, and iv) greater 3D spatial precision during some tasks.

First, participants reported a higher overall positive reaction to the epidural serious game with respect to its system usability (see Section 4.8.1). With respect to game engagement, participants felt greater immersion (the easiest aspect of engagement to endorse, as defined by Brockmyer et al. [11], see Section 3.6), in the learning experience. This increased immersion may be a contributing factor to the shorter task completion times and greater 3D spatial precision found during the room-scale VR setup (see Section 4.8.5).

Specifically, I anticipate the shorter task completion times and improved spatial precision to be a great benefit to the ACLS serious game. The ACLS serious game simulates a medical emergency where time is of the essence in the real-world situation, and being able to facilitate the faster completion of trainee-desired steps within the simulation aligns with this fact. Further, the serious game contains tasks involving pushing small buttons on a computer monitor, a task which would benefit from spatial precision where the trainee feels competent in what they're attempting to do.

5.3 Implications on Simulation & Virtual Simulation

In terms of simulation, the ACLS and epidural serious games demonstrate the benefits of virtual simulation over traditional instructor-led simulation. Results from both of the usability studies suggest that serious games have the power to be a fun, engaging, and usable learner-centric alternative teaching method. Notably, these serious games are great examples of the cost-effectiveness of virtual simulation. Both serious games were developed over a span of several months by a single novice developer. According to a 2014 video game industry salary survey, the average annual income of a game developer within the Canadian video game industry was USD $71k [41]. Compared to just the reoccurring per-year costs of maintaining a dedicated simulation center (estimated at USD $360k, see Section 2.2), paying an experienced industry game developer is both cost efficient and will produce a technically higher quality video game than compared to the two serious games detailed in this thesis developed by a novice.

With specific mention of the epidural procedure preparation serious game, the project illustrates the important need to consider the limitations of computer hardware when designing serious games and simulations, particularly when utilizing VR devices. Although the project aimed for visual realism, limitations in VR HMD display resolution necessitated game play compromises in the form of a magnifier to more easily read on-screen text. In the future, virtual simulations should consider the effects of the hardware being used and the requirements imposed upon it by the desired visual fidelity of the simulation.

5.4 Implications on Virtual Reality

As discussed in Section 5.2, room-scale VR provided some benefits over seated VR which should be taken advantage of. More specifically, room-scale VR, compared to seated VR, increases perceived overall system usability from the trainee's perspective, improves trainee immersion and therefore engagement, provides opportunities of shorter task completion times during tasks which combine multiple methods of interactivity, and provides greater 3D spatial precision during object placement tasks.

In general, the epidural serious game demonstrates the potential of consumer-grade VR devices as teaching tools. Traditionally, the video game industry has been the largest pushing influence of advancing certain technologies such as computer graphics and personal computer audio capabilities. This trend follows suit with the modern VR device companies specifically targeting video game players, with one such example being usable only with a video game console (Sony PlayStation VR, see Section 2.3). Although video game players are historically early adopters of new, exciting, and expensive technologies, VR device companies shouldn't neglect the possibilities in the space of serious games and simulations for learning, especially in the case of the healthcare industry.

5.5 Implications on Serious Games

With respect to serious games, this thesis has primarily demonstrated the window of opportunity afforded by current consumer-grade VR devices. Modern consumer-grade VR devices are affordable, powerful, and will soon be adopted by the mass market. Projections for the growth of the VR hardware industry are staggering, with some research firms suggesting the market to grow to USD $50 billion by 2021 [99]. This is driven largely in part by video game early adopters, though will extend into other industries over time.

To address the needs of future learners, serious games must meet the challenge of growing with the VR industry. One key selling point of serious games is the fact that the average learner has changed within the last few decades to become more independent and tech-focused compared to older generations. Learner-centric approaches to education (including serious games) has become increasingly important, effective, and popular across a wide variety of specialties. With the introduction of the mass-market availability of VR devices, the opportunity to build upon the ability of serious games to be inherently fun, motivating, and engaging must be taken advantage of in order to remain relevant.

5.6 Future Work

Moving forward, further development on the ACLS serious game will continue as it becomes compatible with room-scale VR. This includes integration of the relevant plugins within the Unity 3D game engine (see Section 4.2 for the plugins used in the epidural serious game) to enable HTC Vive capabilities, and game logic according to the hand motion controllers will need to be written. With this, a secondary round of usability study incorporating the latest iteration of changes (detailed in Section 3.8) will be performed in order to re-evaluate the game's usability. Additional study metrics will be incorporated to test for the effectiveness of the serious game as an ACRM skills teaching tool in a pre- and post- evaluation study design.

With respect to the use of VR for serious games and simulations in particular, open questions remain unanswered. Given the growing availability of consumer-grade VR devices in recent years, failing to address these open issues may result in time wasted in developing serious games and simulations which are either ineffective or could be more effective as teaching tools through proper design. Some of these questions to consider are:

- What are the differences between seated and standing VR setups? What about the differences between standing and room-scale VR setups? Which applications, user interactions, and use cases are best afforded by the different setups?

- Is there a relationship between the size of the room-scale VR play space and the virtual environment which is affecting learning outcomes? Is it safe to assume that larger room-scale VR play spaces are better in most scenarios compared to smaller play spaces?

- What clever workarounds exist with respect to modern consumer-grade VR devices which could limit the substantial system resources required to use them? For example, does previous work demonstrating the ability of realistic 3D audio cues to compensate for reduced graphical fidelity without sacrificing perceived realism translate into VR systems?

Chapter 6

Contributions & Conclusion

The work outlined throughout this thesis has shown the positive reactions of users towards both desktop-based and VR-based serious games, and the usefulness of initial usability testing of such games to rapidly find and resolve immediate problems. Secondly, the investigation into the differences between seated and room-scale VR has shown positive effects with respect to a number of factors which should influence what type of consumer-grade VR systems the designers and developers of serious games and virtual simulations should utilize. To summarize the contributions provided in this thesis:

- *ACLS serious game*: A desktop-based serious game was developed to train Anesthesia Crisis Resource Management (ACRM) skills. More specifically, the Advanced Cardiovascular Life Support (ACLS) clinical intervention for the urgent treatment of cardiac arrest, stroke, and other life-threatening medical emergencies. The serious game provides a way for a student to interactively react to a simulated medical emergency within a virtual operating room environment.

- *Five recommendations for general serious games development*: The results of the usability study presented in Chapter 3 led to the development of five separate recommendations which general serious games designers and developers should follow: i) work in an interdisciplinary team, ii) strive for graphical and audio realism as the project requires, iii) aim to include usability options for the most commonly performed tasks, iv) design trainee interactions around standardized controls which they may be familiar with, and v) prioritize usability testing early in the project to uncover the most common issues interfering with a trainee's engagement with the game.

- *Epidural procedure preparation serious game*: An HTC Vive VR-based serious game was developed to teach epidural procedure preparation skills within a virtual environment. The serious game allows for seated, standing, and room-scale VR setups.

- *Increased understanding of the benefits of room-scale VR compared to seated VR*: The results of the usability study presented in Chapter 4 showed four significant differences between seated and room-scale VR implementations of the same serious game: i) increased overall positive reactions to the usability of the system, ii) increased trainee immersion, iii) shorter task completion times during tasks which combined different interaction types (moving the virtual avatar and transporting held objects), and iv) greater 3D spatial precision during held object placement.

- *Five recommendations and three guidelines for serious games developers who wish to employ consumer-grade VR devices*: The results of the usability study presented in Chapter 4 led to the development of five recommendations and three guidelines which serious games designers and developers should follow. The recommendations include: i) work in an interdisciplinary team, ii) allow for explorable interactions based upon motion controls, iii) provide ambidextrous controls, iv) strive for graphical and audio realism as the project requires, and v) work around system limitations with respect to system performance and the capabilities of the VR hardware. The three guidelines drawn from experimental data include: i) prefer room-scale VR if appropriate for the project, ii) utilize motion controls if possible, and iii) combine different types of VR interactions together.

To conclude, I will reiterate and address the thesis statement:

> *The combination of serious games and consumer-grade virtual reality hardware provide a usable, interactive, and engaging simulation environment for anesthesia training.*

In general, the two serious games for anesthesia skills training presented within this thesis have shown the potential for serious games and simulations to be interactive and engaging. Despite being limited perhaps by minor usability issues, both serious games scored highly on all tested aspects of system usability and both the ACLS and epidural procedure preparation serious games demonstrated an initial level of game engagement from participants (see Section 3.7.3, Section 4.8.3). Through rapid iterative development and further user studies, I believe that both serious games will demonstrate a higher level of game engagement and usability. Furthermore, the effect of room-scale VR has been investigated and shown to provide numerous benefits to serious games and simulations (see Section 4.10).

Additionally, I believe the body of work presented within this thesis could indeed address many of the current issues within traditional anesthesia training programs. Traditional simulation programs are expensive, yet virtual simulation and the use of serious games is relatively much cheaper. For example, the ACLS and epidural procedure preparation serious games were developed by a single novice developer and can now be used repeatedly within training curricula as long as computer hardware in the future supports the software. To address logistical issues inherent in traditional simulation such as booking instruction rooms and facilitating numerous faculty and resident availability schedules, anesthetist trainees may take the serious game software outside of the classroom and use it whenever they so desire on their own increasingly affordable devices. In the near future of ubiquitous, powerful, and affordable virtual reality hardware adopted by the general population, learner-centric approaches to education will become essential to a new age of healthcare teaching methodologies.

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Appendices

Appendix A: ACLS Scenario

User plays the role of an anesthesiology resident. Scenario starts with the player in a hallway. Enters the operating room (OR) to replace the current anesthesiologist who is at the end of their shift. The OR is currently in progress with a laparoscopic case that started 30 minutes ago.

As you walk into the operating room, you are greeted by the current anesthesiologist. The surgical team and the circulating OR nurse are busy with the surgery. A handover takes place. The patient is undergoing a laparoscopic procedure under general anesthesia with endotracheal intubation. No specific concerns are mentioned during handover and the anesthesiologist departs, wishing you well.

For the next while, things are stable. You peek over the surgical curtain. The surgeons say 'hi' and tell you things are going to plan. You scan your monitors, check the anesthesia cart to see what drugs have been drawn up, review the anesthesia record, perhaps optimize some settings on the anesthesia machine, check to see there is a phone/telephone number to call your supervising staff in case of unexpected emergency. Everything is going routinely.

Suddenly there is an increase in suction sounds. You look at the suction container and it is filling up with blood. The surgeons appear tense. You hear warning sounds from the anesthesia machine. You glance quickly at the monitors and see multiple alarms including low blood pressure (80/40), tachycardia (HR 130), and low EtCO2 (25).

Concerned with these readings, you inform the surgeons that there is a change in the patient's hemodynamic status. You quickly cycle the blood pressure cuff while changing your machine settings to 100% O2 and turning the inhalation vapor to 0% (OFF). You open your intravenous line to administer fluids.

Meanwhile, the anesthesia machine continues to alarm. The new vital signs on the monitor now show a BP of 20/10, HR 160, the O2 sat probe is unable to give a reading, and the EtCO2 is 20. You ask the circulating nurse to call for help as well as for blood.

The cycling blood pressure cuff is now unable to read a blood pressure. The HR is 160 with a normal sinus rhythm tracing on the EKG. There is also no reading from the SPO2 probe and the EtCO2 monitor. You confirm the blood pressure reading by palpating for a carotid pulse which you cannot locate. You direct the surgical team to begin chest compressions for an intraoperative cardiac arrest. At the same time, you ask the circulating nurse to bring the 'crash cart' into the operating room.

The resuscitation then proceeds along the ACLS algorithm for Asystole/Pulseless Electrical Activity. You ask the surgical team to attach the defibrillation pads to the patient in case the current sinus rhythm devolves into one that is shockable. While the compressions continue, you administer a dose of epinephrine according to the guidelines. You also administer fluids/blood as they become available. The surgeons convert the surgery into a laparotomy in order to control the bleeding. With compressions continuing, the surgical team is able to gain control of the bleeding and the suction sounds stop. Just then, a member of the surgical team reports the return of a femoral pulse. The anesthesia monitor also shows a $EtCO_2$ value of 56 and the blood pressure cuff returns with a reading of 82/50. End Scenario.

Appendix B: ACLS Demographics Questionnaire

Usability Testing of a Serious Game for Advanced Cardiovascular Life Support Education and Training

Demographics Questionnaire

* Required

1. **Please insert your participant number here** *

2. **Age** *
   Mark only one oval.
   - 18-20
   - 21-23
   - 24-26
   - 27-29
   - 30+

3. **Gender** *
   Mark only one oval.
   - Male
   - Female
   - Other:

4. **Are you from the Game Development and Entrepreneurship program at UOIT?** *
   Mark only one oval.
   - Yes *Stop filling out this form.*
   - No *Skip to question 5.*

5. **Are you from one of the Health Sciences programs at UOIT?** *
   Mark only one oval.
   - Yes *Skip to question 6.*
   - No *Stop filling out this form.*

6. **Which health sciences specialty are you pursuing?** *

Appendix C: ACLS Study Questionnaire

Usability Testing of a Serious Game for Advanced Cardiovascular Life Support Education and Training

QUIS, GEQ, SUS

* Required

1. **Please insert your participant number here** *

Overall reactions to the software

2. **Overall reactions to the software** *
Mark only one oval.

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

3. *
Mark only one oval.

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

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	
inadequate power	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	adequate power

6. *
Mark only one oval.

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

7. *
Mark only one oval.

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

Screen

8. **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

9. **Highlighting on the screen simplifies task** *
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	very much

10. **Organization of information on screen** *
Mark only one oval.

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

11. **Sequence of screens** *
Mark only one oval.

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

Terminology and system information

12. **Use of terms throughout system** *
Mark only one oval.

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

13. **Computer terminology is related to the task you are doing** *
Mark only one oval.

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

14. **Position of messages on screen** *
Mark only one oval.

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

15. **Messages on screen which prompt user for input** *
Mark only one oval.

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

16. **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

17. **Error messages** *
Mark only one oval.

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

Learning

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

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

19. **Exploring new features by trial and error** *
Mark only one oval.

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

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

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

21. **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

22. **Help messages on the screen** *
Mark only one oval.

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

23. **Supplemental reference materials** *
Mark only one oval.

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

System capabilities

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

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

25. **System reliability** *

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unreliable	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	reliable

26. **System tends to be** *

Mark only one oval.

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

27. **Correcting your mistakes** *

Mark only one oval.

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

28. **Experienced and inexperienced users' needs are taken into consideration** *

Mark only one oval.

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

System Usability Scale

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

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

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

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

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

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

32. **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

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

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

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

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

35. **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

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

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

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

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

38. **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

Game Engagement Questionnaire

39. **Playing seems automatic** *
Mark only one oval.

- Yes
- Maybe
- No

40. **I lose track of where I am** *
Mark only one oval.

- Yes
- Maybe
- No

41. **My thoughts go fast** *
Mark only one oval.

- Yes
- Maybe
- No

42. **I feel scared** *
Mark only one oval.

- Yes
- Maybe
- No

43. **I feel spaced out** *
Mark only one oval.

- Yes
- Maybe
- No

44. **I lose track of time** *
Mark only one oval.

- Yes
- Maybe
- No

45. **I feel like I just can't stop playing** *
Mark only one oval.

- Yes
- Maybe
- No

46. **Playing makes me feel calm** *
Mark only one oval.

- Yes
- Maybe
- No

47. **I play longer than I meant to** *
Mark only one oval.

- Yes
- Maybe
- No

48. **The game feels real** *
Mark only one oval.

- Yes
- Maybe
- No

49. **I don't answer when someone talks to me** *
Mark only one oval.

- Yes
- Maybe
- No

50. **I can't tell that I'm getting tired** *
Mark only one oval.

- Yes
- Maybe
- No

51. **I really get into the game** *
Mark only one oval.

- Yes
- Maybe
- No

52. **If someone talks to me, I don't hear them** *
Mark only one oval.

- Yes
- Maybe
- No

53. **I play without thinking about how to play** *
Mark only one oval.

- Yes
- Maybe
- No

54. **I feel different** *
Mark only one oval.

- Yes
- Maybe
- No

55. **Things seem to happen automatically** *
Mark only one oval.

- Yes
- Maybe
- No

56. **Time seems to kind of stand still or stop** *
Mark only one oval.

- Yes
- Maybe
- No

57. **I get wound up** *
Mark only one oval.

- Yes
- Maybe
- No

Open Ended

These questions are open ended and are not required to proceed. They are an opportunity for you to provide any additional feedback you wish to give.

58. **Did any part of the game feel especially natural or intuitive?**

59. **Did any part of the game feel especially unnatural or unintuitive?**

60. **Did any part of the game seem especially realistic?**

61. **Did any part of the game seem especially unrealistic?**

62. **Do you have any additional feedback that you'd like to give?**

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Appendix D: Epidural Demographics Questionnaire

Usability Testing of a Virtual Reality-Based Epidural Procedure Preparation Tool

Demographics Questionnaire

* Required

1. **Please insert your participant number here** *

   ....

2. **Age** *

   Mark only one oval.

   - ( ) 18-20
   - ( ) 21-23
   - ( ) 24-26
   - ( ) 27-29
   - ( ) 30+

3. **Gender** *

   Mark only one oval.

   - ( ) Male
   - ( ) Female
   - ( ) Other:

4. **Are you from the Game Development and Entrepreneurship program at UOIT?** *

   Mark only one oval.

   - ( ) Yes *Stop filling out this form.*
   - ( ) No *Skip to question 5.*

5. **Are you from one of the Health Sciences programs at UOIT?** *

   Mark only one oval.

   - ( ) Yes *Skip to question 6.*
   - ( ) No *Stop filling out this form.*

6. **Which health sciences specialty are you pursuing?** *

   ....

Appendix E: Epidural Study Questionnaire

Usability Testing of a Virtual Reality-Based Epidural Procedure Preparation Tool

AR, QUIS, GEQ, SUS

* Required

1. **Please insert your participant number here ***

   ....

Anesthetic Record

2. **What was the patient's name? ***

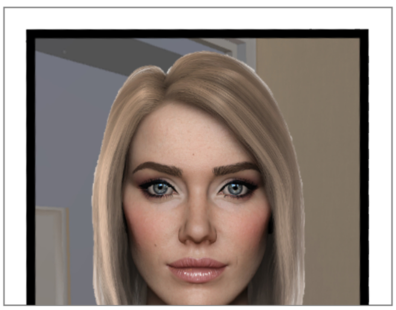
   Mark only one oval.

   - ( ) Cathy Howen
   - ( ) Sara Branh
   - ( ) Erin Thomas
   - ( ) Margaret Wood

3. **What did the patient look like?** *

Mark only one oval.

- ⬭ Option 1
- ⬭ Option 2



- ⬭ Option 3
- ⬭ Option 4

4. **Did the patient have an allergy? If so, to what?** *

Mark only one oval.

- ⬭ No allergy
- ⬭ Wheat, soy
- ⬭ Pollen, dander
- ⬭ Peanuts

5. **Did the patient take any regular medications? If so, what medication?** *

Mark only one oval.

- ⬭ Cromolyn
- ⬭ Benadryl
- ⬭ Insulin
- ⬭ No regular medication

6. **Did the patient have any respiratory problems? If so, what was the problem?** *
Mark only one oval.

- ( ) Smoking history
- ( ) COPD
- ( ) Mild asthma
- ( ) No respiratory problems

Overall reactions to the software

7. **Overall reactions to the software** *
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	
difficult	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	easy

9. *
Mark only one oval.

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

10. *
Mark only one oval.

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

11. *
Mark only one oval.

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

12. *
Mark only one oval.

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

Screen

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. **Highlighting on the screen simplifies task** *
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
not at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	very much

15. **Organization of information on screen** *
Mark only one oval.

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

16. **Sequence of screens** *
Mark only one oval.

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

Terminology and system information

17. **Use of terms throughout system** *
Mark only one oval.

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

18. **Computer terminology is related to the task you are doing** *
Mark only one oval.

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

19. **Position of messages on screen** *
Mark only one oval.

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

20. **Messages on screen which prompt user for input** *
Mark only one oval.

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

21. **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

22. **Error messages** *
Mark only one oval.

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

Learning

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

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

24. **Exploring new features by trial and error** *
Mark only one oval.

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

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

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

26. **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

27. **Help messages on the screen** *
Mark only one oval.

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

28. **Supplemental reference materials** *
Mark only one oval.

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

System capabilities

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

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

30. **System reliability** *
Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	
unreliable	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	reliable

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

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

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

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

33. **Experienced and inexperienced users' needs are taken into consideration** *
Mark only one oval.

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

System Usability Scale

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

	1	2	3	4	5	
Strongly disagree						Strongly agree

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

	1	2	3	4	5	
Strongly disagree						Strongly agree

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

	1	2	3	4	5	
Strongly disagree						Strongly agree

37. **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

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

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

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

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

40. **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

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

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

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

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

43. **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

Game Engagement Questionnaire

44. **Playing seems automatic** *
Mark only one oval.

⬭ Yes
⬭ Maybe
⬭ No

45. **I lose track of where I am** *
Mark only one oval.

- Yes
- Maybe
- No

46. **My thoughts go fast** *
Mark only one oval.

- Yes
- Maybe
- No

47. **I feel scared** *
Mark only one oval.

- Yes
- Maybe
- No

48. **I feel spaced out** *
Mark only one oval.

- Yes
- Maybe
- No

49. **I lose track of time** *
Mark only one oval.

- Yes
- Maybe
- No

50. **I feel like I just can't stop playing** *
Mark only one oval.

- Yes
- Maybe
- No

51. **Playing makes me feel calm** *
Mark only one oval.

- Yes
- Maybe
- No

52. **I play longer than I meant to** *
Mark only one oval.

- Yes
- Maybe
- No

53. **The game feels real** *
Mark only one oval.

- Yes
- Maybe
- No

54. **I don't answer when someone talks to me** *
Mark only one oval.

- Yes
- Maybe
- No

55. **I can't tell that I'm getting tired** *
Mark only one oval.

- Yes
- Maybe
- No

56. **I really get into the game** *
Mark only one oval.

- Yes
- Maybe
- No

57. **If someone talks to me, I don't hear them** *
Mark only one oval.

- Yes
- Maybe
- No

58. **I play without thinking about how to play** *
Mark only one oval.

- Yes
- Maybe
- No

59. **I feel different** *

Mark only one oval.

- Yes
- Maybe
- No

60. **Things seem to happen automatically** *

Mark only one oval.

- Yes
- Maybe
- No

61. **Time seems to kind of stand still or stop** *

Mark only one oval.

- Yes
- Maybe
- No

62. **I get wound up** *

Mark only one oval.

- Yes
- Maybe
- No

Open Ended

These questions are open ended and are not required to proceed. They are an opportunity for you to provide any additional feedback you wish to give.

63. **Did any of your actions or capabilities make you feel powerful or in control?**

64. **Did you ever feel limited in your capability to interact with the game in any way?**

65. **Did any part of the game feel especially natural or intuitive?**

66. **Did any part of the game feel especially unnatural or unintuitive?**

67. **Do you think that virtual reality devices (such as the HTC Vive) would be a benefit or detriment to computer-based learning in any way?**

68. **Do you have any additional feedback that you'd like to give?**

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