TOTAL KNEE REPLACEMENT SERIOUS GAME FOR SURGICAL EDUCATION AND TRAINING

by

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- (E) B. Cowan, H. Sabri, B. Kapralos, S. Cristancho, F. Moussa, and A. Dubrowski. SCETF: Serious game surgical cognitive education and training framework. In *Proceedings of the Third IEEE International Games Innovation Conference*, City of Orange, CA, USA, November 2-4, 2012, pp. 130-133.
- (F) B. Cowan, H. Sabri, B. Kapralos, F. Moussa, S. Cristancho, and A. Dubrowski. A serious game for off-pump coronary artery bypass surgery procedure training. *Studies in Health Technology and Informatics*, 163:147-149, 2011.

- (G) H. Sabri, B. Cowan, B. Kapralos, F. Moussa, S. Cristancho, and A. Dubrowski. Off-pump coronary artery bypass surgery procedure training meets serious games. In *Proceedings of the International Symposium on Haptic Audio-Visual Environments and Games*. Phoenix, AZ. USA, October 16-17, 2010, pp. 123-127.
- (H) H. Sabri, B. Cowan, B. Kapralos, M. Porte, D. Backstein, and A. Dubrowski. Serious games for knee replacement surgery procedure education and training. World Conference on Educational Sciences (WCES) 2010. Istanbul, Turkey, February 4-8, 2010. Appears in Procedia - Social and Behavioral Sciences 2(2):3483-3488.
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Refereed Abstracts

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- (N) Brent Cowan, Hamed Sabri, Bill Kapralos, Fuad Moussa, Sayra Cristancho, and Adam Dubrowski. A serious game for off-pump coronary artery bypass surgery procedure training. Poster presentation - *The Richard K. Reznick Wilson Centre Research Day 2010*. Toronto, Canada, October 22, 2010.

ABSTRACT

Traditionally, orthopaedic surgical training has primarily taken place in the operating room. Given the growing trend of decreasing resident work hours in North America and globally due to political mandate, training time in the operating room has generally been decreased. This has led to less operative exposure, teaching, and feedback for orthopaedic surgery residents. To solve this problem, a 3D serious game that was designed for the purpose of training orthopaedic surgery residents the steps comprising the total knee replacement procedure. Real-time, 3D graphical and sound rendering technologies are employed to provide sensory realism ensuring that the knowledge gained within the serious game can be more easily recalled and applied a real world scenario. A usability study to address user perceptions of the game's ease of use, and the potential for learning and engagement was conducted. Results indicate that the serious game is easy to use, intuitive, and stimulating.

KEYWORDS

Serious games, total knee arthroplasty, knee replacement, virtual simulations, learner-centered teaching, interactive learning.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AI	Artificial Intelligence
AVI	Audio Video Interleave (a video wrapper format created by Microsoft)
CAD	Computer-aided Design
CD	Compact Disk
ED	Emergency Department
GLSL	OpenGL (Graphics Library) Shading Language
HTML	HyperText Markup Language
IPE	Interprofessional Education
ІТТ	Interactive Trauma Trainer
кт	Knowledge Translation
MIST	Minimally Invasive Surgical Trainer
NPC	Non-Playing Character
OPCAB	Off-Pump Coronary Artery Bypass Surgery
OR	Operating Room
QUIS	Questionnaire for User Interaction Satisfaction
SCETF	Surgical Cognitive Education and Training Framework
ТКА	Total Knee Arthroplasty
USD	United States Dollar
VIST	Vascular Intervention System Training
VR	Virtual Reality

1. INTRODUCTION

1.1 MOTIVATION

Total knee replacement or total knee arthroplasty (TKA) is a surgical procedure whereby the painful arthritic knee joint surfaces are replaced with metal and polyethelene components that serve to function in the way that bone and cartilage previously had. The procedure provides reproducible pain relief and improvement in function for patients suffering from painful, deformed, and unstable knees [Park et al., 2007]. According to Dr. Paul A. Manner of the American Academy of Orthopaedic Surgeons, approximately 400,000 knee replacements are performed annually in the United States alone [Manner, 2008]. The procedure has been rated among the most successful surgical interventions across all surgical specialties with respect to reliability of results and patient satisfaction [Lavernia et al., 2000]. In short, TKA involves replacing the articular joint surface of the femur, the tibia and possibly the patella. The TKA procedure is comprised of a number of steps that are followed sequentially and each step may involve the use of a variety of specialized surgical tools and equipment.

1.1.1 TIME AND RESOURCES

The nuances, problem solving, and troubleshooting that surround orthopaedic surgery and surgery in general, are traditionally acquired in the operating room following the *master-apprenticeship model* whereby the resident (trainee) acquires the skills (technical and cognitive), required surgical techniques, and knowledge in the operating room in a *see one, do one, teach one manner*

[Wigton, 1992]. We remember approximately ten percent of what we read, twenty percent of what we hear, and about thirty percent of what we see. But we remember approximately 90% of what we do [Dale, 1969]. Based on the way we learn, the master-apprenticeship model might seem to be ideal. Someone who has mastered a set of skills could pass this skill set on to an apprentice in the most direct way. The apprentice learns by doing and receives instant feedback from the master. Although surgical training has followed the master-apprentice model for more than 200 years, with much of the resident's education taking place in the operating room [Wigton, 1992], such "hands-on" training of residents leads to increased resource consumption (e.g., monetary, faculty time, and time in the operating room). A study by Lavernia et al. [2000] examined the cost of the TKA surgery at US teaching hospitals vs. non-teaching hospitals. They found that patients who underwent surgery at a teaching hospital had higher associated charges (\$30,311.00 ±\$3,325.00 as opposed to \$23,116.00 ±\$3,341.00 in a nonteaching hospital; in US funds), in addition to longer times in the operating room (190 \pm 19 minutes as opposed to 145 \pm 29 minutes in a non-teaching hospital). They attribute the increases in resource consumption to the "hands-on" approach required to train residents. There is a growing trend of decreasing resident work hours in North America and globally due to political mandate [Zuckerman et al., 2005]. This has led to decreased training time in the operating room and hence less operative exposure, teaching, and feedback [Weatherby et al., 2007]. Operative time must then be maximized in order to maintain a high level of surgical training. Although the amount of repetition necessary to obtain the

surgical competence required of residents is still unclear, medical literature suggests that technical expertise is acquired through years of practice [Ericsson et al., 1993] and indicates a positive correlation between volume and patient outcome [Halm et al., 2002]. The *British Medical Journal* pointed out that "before the European Working Time Directive a trainee could expect to work over 30,000 hours between becoming a senior house officer and getting a consultant post" [Hanly, 2003]. The Royal College of Surgeons estimates that this will likely fall to 8,000 hours [Palter and Grantcharov, 2010]. Therefore, residents can no longer expect to acquire all of their knowledge in a purely clinical environment. Residents are now expected to arrive in the operating room pre-trained in order to optimize operative room exposure [Kneebone et al., 2006]. It is evident that given the increasing time constraints, trainees are under great pressure to acquire complex surgical cognitive and technical skills.

Other available alternative methods for surgical training include the use of animals, cadavers, or plastic models; each option with its share of problems [Heng et al., 2004]. More specifically, animal anatomy can vary greatly from humans, cadavers cannot be used multiple times, while plastic models don't necessarily provide realistic visual and haptic feedback [Heng et al., 2004]. Simulation offers a viable alternative to practice in an actual operating room, offering residents the opportunity to train until they reach a specific competency level. Simulations range from decontextualized bench models and virtual realitybased environments to high fidelity recreations of actual operating rooms

[Kneebone, 2009]. Although virtual reality-based technologies have been incorporated in the teaching/training curriculums of a large number of professions (including surgery) for several decades, the rising popularity of video games has seen a recent push towards the application of video game-based technologies to teaching and learning. Serious games, that is video games whose main purpose is not entertainment but rather teaching and learning, leverage the advances made in the video game realm along with the growing popularity of video games, particularly with today's generation of students/learners, to overcome some of the problems and limitations associated with traditional teaching methods, including surgical training techniques.

1.1.2 EDUCATING THE MILLENNIAL GENERATION

Traditional teaching-and-learning environments often do not address the learning needs of the current generation of millennial students (the generation raised in the sensory-flooded environment of digital technology and mass media e.g., the "internet generation" [Prensky, 2005]) who prefer team-work, experiential activities, structure, and the use of technology. Furthermore, traditional classroom teaching environments present a *teacher-centered* approach to learning whereby the teacher controls what is being learned and when. This is in contrast to the fact that such approaches have been proven to be ineffective for today's generation of students who prefer a *learner-centered* teaching approach whereby they (the students) control the learning through interactivity allowing them to learn via active, critical learning [Stapleton, 2004]. The fact that the

millennial generation has always been digitally connected has led to a mindset unlike any that medical faculty have ever seen. Understanding this mindset is an important aspect of educational planning and course development. Specifically, according to Villeneuve and MacDonald [2006], this generation does not remember a time without e-mail, internet, cell-phones, lap-top computers, or video game consoles. In fact, according to a report released by the Kaiser Family Foundation, 83% of 8 to 18 year-olds have a video game console at home, 56% have two or more consoles, 55% own a handheld video game player, and on average, they spend about one hour playing video games every day [Rideout et al., 2005]. Their unique way of being and knowing has largely influenced the learning needs of this generation of students. It is not surprising that this generation views technology as a necessity both in life and learning, and highly regards "doing rather than knowing", making interactive, experiential learning a necessity for their educational success [Mangold, 2007].

1.1.3 A LEARNER CENTERED APPROACH

In contrast to traditional teaching environments wherein the teacher controls the learning (e.g., teacher centered), as previously described, serious games and game-based learning in general, present a learner centered approach to education in which the student, as the player, controls the learning through interactivity. Such engagement may allow the student-player to learn via an active, critical learning approach [Stapleton, 2004]. Game-based learning provides a methodology to integrate game design concepts with instructional

design techniques to enhance the educational experience for students [Kiili, 2005]. Video games provide students the opportunity to learn to appreciate the inter-relationship of complex behaviors, sign systems, and the formation of social groups [Lieberman, 1997]. Games inherently support engagement and if engagement is sustained, it may facilitate experiential learning by providing students with concrete experiences and active experimentation [Kolb, 1984; Squire, 2008]. Furthermore, with respect to students, strong engagement has been associated with academic achievement [Shute et al., 2009]. Similar to a good game designer, an educator should provide trainees/learners with an environment that promotes learning through interaction [Stapleton, 2004]. Virtual environments and video games offer students the opportunity to practice their skills and abilities within a safe learning environment, leading to a higher level of self-efficacy when faced with real life situations where such skills and knowledge are required [Mitchell and Savill-Smith, 2004]. Serious games and simulations may also reduce anxiety by providing the student with an experience that is not unlike a dress rehearsal. Games may allow for instant personalized feedback that students can use to monitor their progress. With these experience-based, instructional methods, faculty work as facilitators, facilitating the experience and subsequent knowledge acquisition. These experience-based methods incorporate more complex and diverse approaches to learning processes and outcomes; allow for interactivity; allow for cognitive as well as affective learning; and perhaps most importantly, foster active learning [Ruben, 1999].

1.2 EDUCATIONAL GAMES

Educational games are games first, meaning that they are designed to be fun. Educational games are generally targeted to young people who are viewed as "averse to learning" by educators [Belotti et al., 2009]. Educational games are typically viewed as a subset of the serious games, and are mainly developed for use in kindergarten to grade twelve education [Ratan and Ritterfeld, 2009]. Education refers to the acquisition of knowledge, while training refers to the acquisition of skills. Educational games generally focus on the acquisition of knowledge while using entertainment as a motivation.

1.3 SERIOUS GAMES

The idea of using games for purposes other than entertainment was first formulated in a book titled 'Serious Games' by Clark C. Abt [1975]. Clark defines serious games by stating: "We are concerned with *serious games* in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement." [Abt, 1975]. The examples discussed by Clark were limited to table-top games as video games were still in their infancy. The first commercially successful video game, Pong, debuted in 1972 [Pully, 2007]. In 2002, motivated by Clark Abt's book *Serious Games*, David Rejeski from the Woodrow Wilson Center for Scholars added the term serious games to a report Ben Sawyer prepared titled "Improving Public Policy through Game-based Learning and Simulation" to give the title a little more "punch" (the revised title was. "Serious Games: Improving Public Policy through

Game-based Learning and Simulation") [Sawyer, 2009]. The expression 'serious games' can be seen as a contradiction or a tautology [Breuer, and Bente, 2010]. If games are fun, how can they also be serious? On the other hand, gamers (people who play video games regularly) certainly take them seriously. It could even be argued that games have an evolutionary background as instruments for survival training [Breuer, and Bente, 2010]. Animals learn to fight and hunt through play.

Although no particularly clear definition of the term is currently available, serious games usually refer to games that are used for training, advertising, simulation, or education and are designed to run on personal computers or video game consoles [Susi et al., 2007]. Serious games have also been referred to as "games that do not have entertainment, enjoyment, or fun as their primary purpose" [Michael and Chen, 2006]. A serious game can more formally be defined as an interactive computer application, with or without a significant hardware component, that i) has a challenging goal, ii) is fun to play and/or engaging, iii) incorporates some concept of scoring, and iv) imparts to the user a skill, knowledge, or attitude that can be applied to the real world [Bergeron, 2006]. Serious games "leverage the power of computer games to captivate and engage players for a specific purpose such as to develop new knowledge or skills" [Corti, 2006]. In addition to promoting learning via interaction, there are various other benefits to serious games. More specifically, they allow users to experience situations that are difficult (even impossible) to achieve in reality due to a number

of factors including cost, time, and safety concerns [Squire and Jenkins, 2003]. Serious games may also support the development of various skills including analytical and spatial, strategic, recollection, and psychomotor skills as well as visual selective attention [Mitchell and Savill-Smith, 2004]. Further benefits of serious games may include improved self-monitoring, problem recognition and solving, improved short-and long-term memory, and increased social skills [Mitchell and Savill-Smith, 2004].

1.4 SIMULATION AND SIMULATORS

Simulation is the process of designing a model (i.e., a description of the system that you wish to study) of a real or imagined system and conducting experiments with that model. The purpose of simulation experiments is to understand the behaviour of the system or evaluate strategies for the operation of the system. Assumptions are made about this system and relationships are derived to describe these assumptions - this constitutes a "model" that can reveal how the system works [Becker and Parker, 2011]. A simulation is typically accomplished through the use of a simulator, that is (according to the Merriam-Webster Dictionary [2012]), a device that enables the operator to reproduce or represent under test conditions phenomena likely to occur in actual performance. Simulators can be either physical or virtual. As previously described in Section 1.1.1, simulation in the context of surgery usually involves cadavers (human or animal), plastic models, or virtual reality. Animal anatomy can vary greatly from humans and cadavers cannot be reused [Heng et al., 2004]. Plastic models can

be expensive to maintain and they require the presence of an expert during the procedure to provide feedback [Kneebone et al., 2006]. Virtual reality simulators tend to be very expensive due to the need for custom haptic devices and are usually specialized to one type of procedure such as laparoscopy. Many institutions simply cannot afford virtual reality simulators. Due to such costs, student access is limited, and simulators generally cannot be taken home for further study like text books, and videos. In fact, despite the fact that medical education has lagged behind with respect to the adaptation of new technologies such as virtual reality and gaming and are resistant to change, virtual reality has been widely and successfully used for training and education in a variety of industries including nuclear, aviation, and military, for many years [Ziv et al., 2003; Smith, 2009]. Sir Liam Donaldson, England's chief medical officer stated that "there was one training simulator for every 300 pilots, compared to just one for every 7,300 doctors" [British Broadcasting Corporation, 2009].

Similar to simulators, serious games can be used to simulate real-world environments and events. The main difference is that serious games do not usually require the user to physically perform each task. For example, a serious game to teach driving might allow the user to steer a car around a virtual city using a mouse and keyboard. A driving simulator would likely have the user controlling the car with a steering wheel and pedals. The steering wheel would likely have haptic feedback allowing the user to feel the resistance, as well as vibration caused by bumps in the road. Simulators generally attempt to model a

physical environment as well as a virtual one. As such, simulators are able to teach both psychomotor and cognitive skills, while serious games are generally limited to the development of cognitive skills only.

Simulation's greatest strength is also its greatest weakness. Increased realism leads to increased costs, which in turn limits access. A serious game can be created to run on almost any home computer and without the need for specialized input devices. Serious games can be made affordable enough to allow students to take the game home for further study. But unlike books and videos, serious games are interactive, and they can force the user to make decisions, such as diagnosing an illness based on symptoms within a fun and engaging environment.

1.5 KNEE REPLACEMENT SERIOUS GAME

In 2010 we were approached by two orthopaedic surgeons, Dr. David Backstein and Dr. Mark Porte from the Department of Surgery, University of Toronto and Mount Sinai Hospital and health professions expert Dr. Adam Dubrowski from the Learning Institute, The Hospital for Sick Children, and the Faculty of Medicine, University of Toronto, to develop a serious game for total knee arthroplasty (replacement) procedure training. Their motivation for the game was related to the fact that they have noticed that despite being told orthopaedic surgery residents are told to read about the total knee replacement procedure in their textbooks prior to their scheduled learning time in the operating room, they typically arrived ill prepared. Operating room access is a limited resource and the experts (Dr. David Backstein, Dr. Mark Porte, and Dr. Adam Dubrowski) found that far too much time was being wasted going over material that the residents were expected to know, specifically the steps and the tools required at each stage of the operation. Given the issues associated with surgical training (apprenticeship model, costs, etc.), and the potential benefits associated with serious games (student-centered approach, etc.), we began working on the serious game for the TKA procedure. The purpose of the game was to teach orthopaedic surgery residents the series of steps comprising the TKA procedure. All of the educational content used in the TKA game was provided by Dr. Backstein Dr. Porte, and Dr. Dubrowski (referred to as context experts). This content includes text based multiple choice questions, explanations, diagrams, audio, and video instruction.

The intended audience for the game was orthopaedic surgery residents who may not necessarily be "gamers", that is, avid video game players, and may not necessarily have a high degree of "computer literacy" (as described by the expert consultants). Computer literacy is not a requirement of the orthopaedic surgery program at the University of Toronto and aside from .the ability of residents to use a word processor and check their e-mail, no other assumptions were made regarding the residents' prior computing experience. They could not be expected to install and uninstall software or hardware. In addition, no lecture time would be devoted to providing any game related instruction and therefore, the TKA serious

game had to be designed to limit any required training for its use. Everything required of the player to play the game (i.e., instructions) had to be incorporated into the game itself so that users can easily learn to play the game on their own without explicit instruction.

A further requirement set out by the content experts was the incorporation of a situated learning approach whereby the learning environment was to modeled after the context in which the knowledge is expected to be applied [Brown et al., 1989; Dalgarno and Lee, 2010; Lave and Wenger, 1991; Ruzic, 1999]. In other words, given that the trainees would be applying their acquired knowledge and skills in an operating room, the serious game places the trainee in this same context, taking on the role of the surgeon, that is, within a high fidelity 3D virtual operating room. 3D technologies (graphical and sound rendering) were required to provide sensory realism consistent with the real-world ensuring that the knowledge gained within the serious game can be more easily recalled and applied when the trainee is placed in the real world scenario [Dalgarno and Lee, 2010]. Although high fidelity/quality rendering of visuals and sound does increase computational requirements, there is also evidence indicating that higher-fidelity graphics serve to focus (the trainees') attention initially, although other attributes are required to sustain attention for longer periods of time [Raths, 2006]. The requirements for a situated learning approach with high fidelity 3D graphics and sound rendering eliminated the potential for simply employing a web-based

interactive tutorial about the procedure which may have also included videos outlining the various steps of the TKA procedure.

With the assumptions and requirements as set out by the context experts, work began on the TKA serious game. An "iterative test-and-design" method was employed whereby the serious game was refined during the design and implementation phase based on the results of a usability study that was conducted with game development experts and orthopaedic surgery residents to gauge initial user perceptions of the game's ease of use, and the potential for learning and engagement. In addition to assisting in the development phase, usability test results indicated that the serious game is easy to use, intuitive, and stimulating.

From an educational perspective, it is believed that by learning the total knee arthroplasty procedure in a fun and interactive "first-person" gaming environment" the trainees will have a better understanding of the cognitive process and ability to focus solely on the technical aspects of learning and will therefore be able to focus on the technical aspect of the procedure in higher fidelity physical models or in the operating room (this will be tested in the future).

Realistic graphics may help to focus a trainee's attention, provide an increased sense of immersion, and allow for situated learning, but it comes at a cost. More specifically, higher fidelity models take longer to develop/produce, increasing

both the cost and the development time of serious games. This was clearly evident during the design and development of the TKA serious game. In addition, higher fidelity and more complex models and environments require greater computational processing to render at interactive rates. This restricts the type of devices capable of supporting serious games containing such high fidelity environments. However, just how important are high fidelity environments to facilitate a situated learning approach? In other words, what effect will a reduced fidelity environment have on learning? Furthermore, virtual environments are typically multi-modal, including, at the very least, both visuals and sounds. What are the implications of multi-modal interactions? In the real world, visuals and auditory stimuli influence one another. Various studies have examined the perceptual aspects of audio-visual cue interaction, and it has been shown that sound can potentially attract part of the user's attention away from the visual stimuli and lead to a reduced cognitive processing of the visual cues [Mastoropoulou et al., 2005]. Given such questions regarding the effect of high fidelity environments and multi-model interactions on learning, and the potential implications and, the potential to limit computational requirements by incorporating lower fidelity environments in particular, the TKA serious game motivated us to examine these issues further within the context of surgical procedure training. More specifically, it led to the development of a multi-modal, serious game surgical cognitive education and training framework (SCETF). Domain-specific surgical "modules" can then be built on top of the existing framework, utilizing common simulation elements/assets and ultimately reducing

development costs. The SCETF focus is on the cognitive components of a surgical procedure and more specifically, the steps comprising a particular surgical procedure, the anatomical and physiological knowledge, and the tools/equipment required at each step/stage of the procedure. By clearly understanding the steps of a procedure and the surgical knowledge that goes along with each step, trainees are able to focus solely on the technical aspect of the procedure (i.e., the actual execution) in higher fidelity models or in the operating room thus making more efficient use of the limited available resources. The SCETF is also being developed as a research tool where various simulation parameters (e.g., levels of audio/visual fidelity) can be easily adjusted allowing for the controlled testing of such factors on knowledge transfer and retention and this will ultimately lead to more effective serious games.

Within the scope of this thesis, using a preliminary version of the SCETF and a modified version of the TKA serious game (the TKA serious game was converted to a module within the SCETF framework), an experiment was conducted to examine the effect of sound on visual fidelity perception within a virtual environment while performing a simple task.

1.6 THESIS CONTRIBUTIONS

There are three primary contributions of this thesis. First, is the development of a serious game for total knee arthroplasty (TKA) (replacement) education and training. The design of the game was dictated by the explicit restrictions set out

by the content experts and included the requirement of a high fidelity virtual environment to facilitate a situated learning approach. Preliminary usability studies conducted with orthopaedic surgery residents and game development students indicate that the game is intuitive, easy to use, and informative. The development of the TKA serious game and its acceptance by others, most notably surgeons in other surgical fields, led to the second contribution of this thesis, and more specifically, the start of the development of the serious game surgical cognitive education and training framework (SCETF) to allow for the development of similar serious games by re-using common elements/assets (i.e., sound and visual rendering, etc.), thus reducing development time and costs. Using a preliminary version of the SCETF and a modified version of the TKA serious game, a study (with human participants) was conducted to examine the effect of sound on visual fidelity perception within a virtual environment while performing a simple task. The results of this study, led to the third contribution of this thesis. More specifically, results revealed that although background sound did not have any effect on visual fidelity, background sound consisting of white noise had a negative effect on the time required to complete a simple task within a virtual environment. Greater details regarding these three contributions are outlined in the reminder of this thesis.

1.7 ORGANIZATION OF THESIS

The remainder of the thesis is organized as follows. In Chapter Two, a background/literature review is provided. An overview of existing serious games

and simulations relating to healthcare in general and surgery specifically is provided. These games represent the state of the art, and their design has greatly influenced the creation of the total knee arthroplasty (TKA) serious game. The TKA serious game is described in greater detail in Chapter Three, where details regarding the reusable components that form the foundation of the serious game surgical cognitive education and training framework (SCETF) are provided. Chapter Four provides the details of two studies. First, a usability study designed to measure user perception of the serious game while gaining valuable feedback on the interface and overall design was conducted. A second study makes use of a preliminary version of the (SCETF) to investigate the perceptual aspects of audio-visual cue interaction. The results of both studies and their implications are discussed in Chapter Five. Concluding remarks, and plans for future research are provided in Chapter Six.

2. BACKGROUND

Despite its relatively recent adoption to the field of game development, serious games (and virtual simulations in general) have been used by the United States military, medical schools, and within academia before the term was introduced [Bergeron, 2006]. Battlezone, a 3D tank game created by Atari in 1980 was adapted to train army gunners, and is widely regarded as the first serious video game [Stone, 2005] (see Figure 1). Serious games have since been used to train medical professionals how to diagnose symptoms, interact with patients, or even perform surgical procedures. Some of the more notable medical games are described below.



Figure 1: Atari's Battlezone screen shot [RetroCpu, 2012].

2.1 SERIOUS GAMES FOR CLINICAL EDUCATION

2.1.1 CYBERSURGEONS

CyberSurgeons is a serious game developed by the Center for Educational Technologies at the Wheeling Jesuit University to teach high school students about health and healthcare [Calinger, 2009]. Students are presented with cases that are relevant to their courses and grade level. Each case provides background information on a patient, medical charts, and a description of their current condition. The student must examine the patient, diagnose the source of the problem, and suggest treatment options. Then the game jumps forward six months allowing the student to revisit the patient and see the result of the treatment plan they selected. A record is kept of the student's choices for grading and to facilitate further discussion.

2.1.2 RISKDOM-GERIATRICS

Home visitations are an essential component of geriatric care. Medical students rarely conduct a home visit as part of their medical training despite the increased need due to an aging population. A serious game called Riskdom-Geriatrics was developed by the University of Sydney to train medical students about geriatric home visits. The students are asked multiple choice questions before entering the virtual house. Once inside, they are expected to click on those elements that they consider to be risk factors for falls, or any items that could be harmful for the patient. More than 70% of the students surveyed said that they learned from the

experience, and would like to see more medical games in the future [Duque, et al., 2008].

2.1.3 JUNIOR DOCTOR MEDICAL SIMULATOR

Junior Doctor medical simulator (JDoc) is a serious game that educates the player about diagnostic procedures and medical criteria required while working on-call in a hospital ward [Sliney, 2008]. The player can navigate within the 3D hospital, viewing the environment and patients from a first-person perspective. As part of the diagnostic procedure, the player can choose from a list of pre-defined questions to ask the patient who will respond with a pre-programmed answer. The player can examine the patient or order tests to aid in diagnosis. The feature that makes JDoc exceptional is the ability to build new scenarios without any programming. The built-in content manager allows newly created scenarios to be shared, so that there is the potential for a large user base to create a never ending supply of new content.

A study was conducted to assess the perceived educational value of a JDoc simulation training session weeks after completion. 1st and 2nd year residents were given a half-day of training using JDoc which covered basic medical emergencies. A questionnaire was completed by 22 participants, 2 to 21 weeks later (10.4 weeks mean). The participants indicated that they perceived educational value from the simulation session [Shah, et al., 2011].

2.1.4 VIRTUAL EMERGENCY DEPARTMENT

Despite the many advancements in medical technology, patient deaths often occur due to human error. A report by the Committee on Quality of Health Care in America estimates that "each year, 98,000 people die because of medical errors occurring in hospitals." [Kohn et al., 2000] Communication errors occur in about 30% of medical team exchanges and many of these failures result in situations that put the patient's life at risk [Guise, and Segel, 2008]. Recognizing the importance of communication, Virtual Emergency Department (ED) uses technology adapted from online gaming to allow a group of students to work together to diagnose and treat virtual patients [Heinrichs et al., 2007]. ED allows students to voice chat (speak to each other across the network using a headset) so that communication is fast and natural. The online aspect of ED allows multidisciplinary teams of nurses and physicians at different facilities to manage a variety of trauma cases together. Students command their avatar by selecting options from a menu and the avatar then performs the task. The procedure can be monitored for evaluation purposes by an instructor.

A study was conducted to compare the performance of students trained using ED to that of students trained with high-fidelity patient simulators (PSs). Thirty students were randomly divided into two groups and the performance was measured using pre- and post-testing. Students who used either the ED or the PS showed significant improvement in performance. In addition, there was no significant difference in performance between the two groups, suggesting that the
online ED may be as effective for learning team skills as the more expensive patient simulators [Youngblood et al., 2008].

Building upon the success of ED, ED II was developed to train participants to respond to a chemical, biologic, radiologic, nuclear, or highly explosive incident. Students are required to triage patients based on the severity of their injuries.

2.1.5 EMERGENCY ROOM: CODE RED

Legacy Interactive has produced several serious games involving the diagnosis and treatment of patients [Legacy Interactive, 2012]. Unlike most of the games covered in this review, Legacy's games are not developed as part of a research study or commissioned by a government agency; they are instead commercial products. Legacy's latest instalment of the Emergency Room series is 'Code Red' which retails for approximately \$20 US. Code Red allows the player to treat 35 different conditions in a photorealistic 2D point-and-click environment (see Figure 2). Although the scenarios presented in the series are created by emergency room (ER) doctors to be realistic and educational, Code Red is marketed to the wider layperson market.



Figure 2: Emergency Room: Code Red by Legacy Interactive, in-game screen shot taken from [Legacy Interactive, 2012].

2.1.6 INTERACTIVE TRAUMA TRAINER

Interactive Trauma Trainer (ITT) is a serious game developed by TruSim (a division of Blitz Games Studios), in 2005 for the purpose of training military medical personnel [Ministry of Defence London, 2006]. ITT is based around the procedures and critical decisions that need to be made within the first six minutes to save the life of a battlefield casualty. It focuses on the decision making processes as well as the steps taken to properly diagnose and treat a patient. Players receive a score based on the tasks they performed and the timing of each intervention. In addition to educating the player about medical procedures, games such as ITT help prepare personnel to cope with stressful situations.

2.1.7 TRIAGE TRAINER

Triage Trainer is a prototype also designed by TruSim in 2007, to train first responders how to prioritize medical care during a major catastrophe [TruSim, 2010]. The game takes place on a crowded street where an explosion has just occurred (see Figure 3).



Figure 3: Triage Trainer in-game screen shot, taken from [TruSim, 2010].

The player must prioritize patients based on the severity of their condition. Players can take a patient's vitals, ask them questions, and observe their behaviour. Players receive a score based on the accuracy of their assessment and the time taken to complete their assessment. Triage Trainer is different from most medical simulations in that there is a strong visual component to the assessment of the patient. Cutting edge graphics allow the player to pick up on subtle clues such as changes in the patient's skin pigmentation.

A study was conducted by Coventry University to compare the outcome of participants who were trained using Triage Trainer versus the more traditional card-sort method. Card sorting involves the collection of medical data from mock patients. Each patient is then assigned a coloured card indicating their priority level. All of the 91 participants were medical professionals (doctors, nurses, and paramedics) who may at some time in their career be required to attend the scene of a major accident or terrorist attack. The participants were randomly divided into two groups. One group was trained using the Triage Trainer serious game, and the other group trained using the traditional card-sort exercise. The training was followed by an evaluation whereby participants were required to triage eight casualties in a simulated live exercise. The accuracy of participants who underwent the serious game based training was significantly higher than those who trained using the card-sort exercise [Knight et al., 2010].

2.1.8 HUMAN-SIM

HumanSim is a software simulation platform that provides an initial, refresher, and sustained medical education and training [Virtual Heroes, 2008]. The simulation employs the latest in gaming technology and was designed for use by a wide range of health care students and professionals including physicians, nurses, emergency medical personnel, and first responders. Figure 4 provides a

screenshot from the game which demonstrates the level of graphical realism achieved using the Unreal 3 game engine.



Figure 4: HumanSim in-game screen shot. Taken from [Virtual Heroes, 2008].

HumanSim allows the player to practice scenarios in a safe environment where they do not have to fear the consequences of failure. The game is primarily geared toward first responders, but it is relevant to community health nurses as well.

2.1.9 PULSE

Pulse is an immersive virtual learning space (i.e., a serious game) for clinical skills training (see Figure 5). Pulse was funded by the United States Office of Naval Research and developed by BreakAway Games and Texas A & M

University - Corpus Christi with a budget of ten million dollars [Texas A & M University Corpus Christi, 2008].



Figure 5: PULSE!! In-game screen shot. Courtesy of BreakAway Games [2012].

Cutting-edge graphics recreate a lifelike, environment where civilian and military heath care professionals can practice clinical skills in order to better respond to injuries sustained during catastrophic incidents, such as combat or bioterrorism. The virtual patients will die if they are misdiagnosed, or if the player does not work fast enough to save them. Pulse attempts to recreate the chaotic and stressful environment of a real emergency room.

2.1.10 NOTES

Many of the serious games presented in this review have been developed using expensive commercial game engines such as Unreal [Epic Games, 2012] and Crytech [Crytek, 2012]. Game engines abstract all of the low level functionality needed to make a game such as collision detection, and the loading and rendering models for the user. Using a game engine allows developers to build a game much faster while making use of built in visual effects. However, licensing fees to use these engines commercially are prohibitively expensive. This tends to limit the serious games that rely on these engines to non-profit ventures. Most major game engines offer affordable licensing for non-profit applications and many are free for non-commercial use.

2.2 SERIOUS GAMES FOR SURGICAL EDUCATION

Many serious games for surgical education have been created. Each game is usually specific to one procedure. However, these games are often not targeted to medical professionals. In many cases they employ colourful cartoonish graphics to reduce the level of "gore". The target audience in many cases is high school students interested in pursuing a career in medicine. The steps taken to perform the procedures and the tools used can be accurate and therefore could be used for training. Patients are often referred to these games in order for them to better understand a surgical procedure.

2.2.1 EDHEADS: KNEE SURGERY

EdHeads is a non-profit organization that creates serious games targeted to high school students [EdHeads, 2012]. All of their games are free and run within a web browser so that players do not have to install them on their machines.

EdHead games deal with a variety of science topics, everything from weather to biology. To date they have created three other games specific to surgical procedures; hip replacement surgery, hip resurfacing, and brain surgery. Their games are two dimensional and cartoonish in appearance (see Figure 6), however the steps, tools, and terminology are accurate.



Figure 6: EdHeads Virtual Knee Surgery Game. Taken from [Edheads, 2012].

The EdHeads knee surgery game provides instructions for each step which involves using the mouse to click on the correct surgical tool, drag tools to the correct location, or perform a simple gesture. In order to make the incision for example, the player must use the mouse pointer to draw a line on a picture of a knee where the incision should be made. Acting out each task may make the game more fun to play, but according to our content experts, these actions likely have no educational value. The EdHeads knee surgery game can be used to provide a basic understanding of the procedure and the steps involved. However, additional learning materials would need to be added to the game in order for it to be relevant for clinical instruction.

2.2.2 CORONARY BYPASS SURGERY GAME

The Australian Broadcasting Corporation commissioned a serious game in which the player takes on the role of a surgeon performing a coronary bypass surgery [The Australian Broadcasting Corporation, 2012]. The graphics are cartoonish with a limited colour palette (see Figure 7). The game takes the player through the procedure's thirteen steps beginning with preparation for the surgery and ending with patient recovery.



Figure 7: Coronary Bypass Surgery Serious Game. Taken from [The Australian Broadcasting Corporation, 2012].

At each stage, the player is provided with instructions. Players perform the simplified steps using their mouse to drag and position surgical instruments or select the appropriate starting point for the task. Players have to draw a line on the body to highlight the location of the incision for example. Three levels of difficulty are provided which vary the accuracy and speed that is expected from the player.

There are many big budget games developed for medical professionals (e.g. Triage Trainer, Pulse!, Human-sim) that train users to provide first aid, triage patients, or diagnose illness. But there are currently very few serious games designed to teach surgical procedures to medical professionals.

2.2.3 Virtual Dental Implant Training Simulation

The Virtual Dental Implant Training Simulation was developed by BreakAway games in concert with the Medical College of Georgia [BreakAway Games, 2012; Silver, 2010]. Students are trained in the technical aspects of the procedure with a variety of patients and scenarios. Each of the four patients has a distinctly different personality and medical background. Players are scored on the accuracy of the steps and tools used in the procedure (see Figure 8). The game is free to universities through Noble Biocare (a company specializing in dental implants), and it is already in use in thirteen campuses worldwide [Ivanhoe Newswire, 2011].



Figure 8: Virtual Dental Implant Training Simulation. In-game screen shot taken from [BreakAway Games, 2012].

This game is unique in that blood and gore is used as a form of feedback to the player. Players must also remember to adequately communicate to their virtual patient in order to get a good score. Virtual Dental Implant Training Simulation has highly realistic 3D graphics and animation.

2.3 VIRTUAL SIMULATION FOR SURGICAL EDUCATION

Simulators generally attempt to model a physical environment as well as a virtual one. Virtual reality simulations often use specialized haptic devices and/or stereoscopic visualizations to increase realism. A virtual reality simulator is a combination of hardware and software that allows the user to physically perform a procedure thereby transferring both psychomotor and cognitive skills.

Standardization is one major advantage of simulation in medical training. Surgical training has always varied greatly based the instructors and the resources on hand. Simulators have proven to increase "trainee confidence, competence, and improve patient safety" [Sliney, 2008]. Surgical simulation requires tremendous accuracy compared to other types of simulation. If the haptic feedback is not entirely realistic, the simulator will not efficiently transfer psychomotor skills to the user [Delingette, 1998]. Far worse is the possibility that simulators could teach students incorrectly if the simulated tools and tissue do not behave realistically [Delingette, 1998].

The design of a surgical simulation poses many technical challenges. The simulation of real-time fluid dynamics is still too computationally expensive for consumer grade hardware [Müller et al., 2003]. Dynamic mesh deformation and segmentation is required to allow surgeons to bend and cut soft tissue in a realistic way. The need for realistic physics, haptic feedback, and custom input devices greatly increases the cost.

2.3.1 A GENERAL PURPOSE SURGERY SIMULATOR

Daniel Bielser et al. [2002], developed a general purpose surgery simulator that features topological flexibility and accuracy for tool-tissue interactions occurring during open surgery procedures. The physics and haptics rendering can be run on a separate computer connected by a TCP/IP connection. Dividing the rendering and physics between two computers allows the simulation to run on consumer grade hardware. Alternatively, one high-end desktop computer could run the entire simulation. A PHANToM, which is a general purpose haptic device, provides input and feedback for all the surgical instruments used by the simulation. Highly detailed flesh can be cut and manipulated in stereoscopic 3D. Using the PHANToM instead of custom made haptic devices greatly reduces the cost of the system.

2.3.2 ENDOSCOPY

Endoscopic, or minimally invasive surgery has been shown to shorten recovery time and reduce pain when compared to traditional surgical techniques [Meadows, 2002]. Instead of cutting patients open, endoscopy allows surgeons to operate through small incisions [Meadows, 2002]. A small fibre optic camera is inserted into the patient providing a magnified internal view that is displayed on a computer monitor. Abdominal endoscopy, otherwise known as laparoscopy was first performed in the 1980s, and has since become routine [Meadows, 2002]. Carbon dioxide gas is often pumped into the abdomen inflating it like a balloon which elevates the abdominal wall providing a space for surgical instruments to move freely. Richard Satava stated that "laparoscopic surgery is a transition technology that marked the beginning of the information age revolution for surgery" [Satava, 1999].

2.3.3 MINIMALLY INVASIVE SURGICAL TRAINER

Minimally Invasive Surgical Trainer–Virtual Reality (MIST VR) is a laparoscopic surgical training system [Gallagher et al., 2005]. MIST VR does not attempt to simulate a surgical procedure, but rather, it is used to practice psychomotor skills (see Figure 9). Subjects who trained on the MIST VR have been shown to work faster and with fewer intraoperative errors [Gallagher et al., 2005].



Figure 9: Minimally Invasive Surgical Trainer–Virtual Reality (MIST VR). Taken from [Kanumuri et al., 2008].

A study was conducted with eleven surgeons, 18 medical students and seven non-medical personnel over a two-week period. Each participant trained using MIST for ten sessions lasting twenty minutes each. A score was calculated for each session based on the number of errors and the total time taken, Overall scores reflected surgical experience which suggests that the simulator is measuring surgically relevant parameters [Chaudhry et al., 1999].

2.3.4 VASCULAR INTERVENTION SYSTEM TRAINING

Other simulators such as VIST (Vascular Intervention System Training) also allow surgeons to practice laparoscopic surgery while providing the context of a surgical procedure. VIST displays photo realistic organs that can be cut and sutured (see Figure 10). Fluid simulation adds to the realism with bleeding and cauterization. VIST may be the most sophisticated medical simulator to date which is reflected in its cost. VIST costs \$300,000 US per unit which is prohibitively expensive for many institutions [Gallagher et al., 2005].



Figure 10: Vascular Intervention System Training (VIST). Taken from [Chaer et al., 2006].

Seventeen surgical residents completed a questionnaire before and after performing a surgical procedure on the VIST simulator. Results indicated a strong correlation between the surgical skills demonstrated using the simulator and prior experience [Tedesco et al., 2008]. This suggests that simulators such as the VIST can be used for surgical skill assessment.

2.3.5 SIMULATORS FOR TECHNICAL SKILL ASSESSMENT

Surgical residents are often tested on their knowledge and decision making, but they are rarely evaluated on the technical skills a surgeon requires [Ziv et al., 2003]. This is due to the fact that technical ability is difficult to measure objectively. In order to test skills such as depth perception and manual dexterity as they relate to endoscopic surgery, a game based on an endoscopic sinus surgery was created [Fried, 2004]. Instead of manipulating organ tissue, the game presents an abstract virtual environment filled with simple shapes such as cubes and spheres. The user has to move the objects around and use various tools on them. There are several levels of difficulty and players are given a numeric score that can be used to track their progress.

2.4 VIRTUAL SIMULATIONS SPECIFIC TO ORTHOPAEDIC SURGERY

This section will focus on virtual simulations that are specific to orthopaedic surgery.

2.4.1 VIRTUAL KNEE JOINT REPLACEMENT SURGERY

[Park et al., 2007] present a virtual simulation system for total knee replacement. Their system is based on mechanical computer-aided design (CAD) software and implemented using basic CAD functionality such as shape modeling, assembly, automation, etc., allowing surgeons to determine important surgical parameters prior to the operation itself.

2.4.2 A VIRTUAL REALITY PLATFORM FOR

UNICOMPARTMENTAL KNEE REPLACEMENT SURGERY

Ting et al. [2003], describe a virtual reality system for unicompartmental (partial) knee replacement surgery training using a typical PC-based system and low-cost, six-degrees of freedom (motion), and three-degrees of freedom (force/resistive) manual manipulator. They model both the soft and skeletal tissue of the knee (based on computerized tomography scans) in addition to an assortment of surgical tools. Using the manual manipulator, trainees are able to interact with the model, performing the surgical steps.

2.4.3 VR ARTHROSCOPIC KNEE SURGERY SIMULATORS

In addition to virtual simulations/serious games for total knee arthroplasty, a number of virtual simulations have been developed for arthroscopic knee surgery. Mabrey et al. [2000], developed a virtual reality system for arthroscopic knee surgery that consists of a typical PC, video display, and two force-feedback haptic devices. Forces that would normally be applied by the surgeon to the lower limb during the arthroscopy procedure are directed to a surrogate leg. Proprietary software provides a mathematical representation of the real-world while mimicking the mechanical, visual, and behavioural aspects of the knee.

Cannon, et al. [2006], describe the development of an arthroscopic virtual reality knee simulator to train orthopaedic residents arthroscopic surgery techniques before they begin to practice with "live patients" in the operating room. Their simulation employs realistic human knee models derived from the US National Library of Medicine's Visible Human Dataset. Arthroscopic virtual simulations have also been developed by Zhang et al. [2003] and Heng et al. [2004].

2.5 SUMMARY

Virtual reality now allows surgeons to practice their skills and make their mistakes on virtual patients. The success of the MIST VR, and VIST simulators has proven that virtual reality can be used effectively to teach medical procedures and surgical skills. However, simulators typically cost between \$200,000 to \$400,000 USD [Chaer et al., 2006] and many training institutions cannot afford them. Serious games can be distributed cheaply and played using personal computers or even mobile devices. Unlike simulators, serious games typically do not require any specialized devices to be played. The total knee arthroplasty (TKA) serious game presented here can be played on a typical home computer using the mouse and keyboard.

3. THE SERIOUS GAME FOR TOTAL KNEE ARTHROPLASTY

Our total knee arthroplasty (TKA) serious game is intended to serve as a memory aid to students learning the TKA procedure and to be used in conjunction with other "traditional" learning materials including books and videos. The TKA procedure itself is comprised of a number steps which are generally performed sequentially. The goal of the TKA serious game is for the user/trainee to successfully complete the TKA procedure, focusing on the ordering in which steps are performed and on the tools required to perform each step as opposed to the technical aspects of the procedure, while maximizing their score (points are either added or taken away based on the trainee's (player's) actions). There is also a mechanism in place to allow "games within the game" (i.e., sub-games) whereby at various points in the game, the user is presented with a "sub-game" that requires them to perform a small task related to the step they are currently performing. Currently, sub-games are restricted to one or two multiple choice questions randomly selected from a pre-defined list of questions. Answering these multiple choice questions correctly allows the user to accumulate further points to their score.

3.1 PROJECT CONSTRAINTS

There were a number of constraints imposed by our content experts as well as the intended audience of orthopaedic surgery residents. The game's interface needed to be simple enough to be used by students who may not have any background in computers. Students are expected to use this software on their own home computers. Therefore the amount of detail used in the recreation was limited by the computing power of the home computers students would typically own. The major project constraints are listed below in order of importance.

Educational Materials

The game must contain all of the learning materials provided by our content experts, including multiple choice questions and answers, diagrams, audio, and video instruction.

Ease of Use

The game must be easy to play. The interface and controls need to be easy to learn, as no lecture time would be devoted to game related instruction. All instructions required to play the game must be built into the game itself.

Realistic 3D Graphics

Our content experts requested that the game's environment be modelled after a specific operating room at Mount Sinai hospital.

Hardware Limitations

The game is intended to run on the student's home computer, and this home computer may be several years old. . It was therefore decided that the game should operate on a typical home computer that is five years old (at the time of

this writing) or newer. In order to support hardware older than five years, we would have had to eliminate visual (shader) effects that greatly improve the image quality of the rendered scene.

Distribution

The game may be distributed on a CD or downloaded from the internet (an easyto-use installer program is provided, but the game can also be played directly from the CD).

3.2 OVERVIEW

Users begin the serious game in the operating room taking on the role of the orthopaedic surgeon, viewing the scene in a first-person perspective. The world is viewed through the viewpoint of the user's avatar and as such, the avatar's body is not viewed (but their hand is). Several other non-player characters (NPCs) also appear in the scene including the patient (lying on a bed), assistants, and nurses (see Figure 11). Currently, the NPCs are not animated and are not user controllable. Future versions will allow them to be controlled remotely by other users or controlled using artificial intelligence techniques. The user/trainee has the ability to move and rotate the "camera" using the mouse in a first-person style thus allowing them to move within the scene. A cursor appears on the screen and the trainee can use this cursor to point at specific objects and locations in the scene.



Figure 11: The TKA serious game environment as seen from the user's avatar in a firstperson perspective. Here the NPCs, Surgeon's (user's) hand, and pointer are shown.

Objects that can be selected will appear to glow when the cursor is placed over them. "Selectable objects" include the NPCs (assistants and nurses) in addition to the surgical tools. When a highlighted object is clicked, a menu appears providing a list of selectable options for this particular object. For example, clicking on a nurse or an assistant allows the user to interact with them (e.g., the user can "ask" the nurse to hand over a particular tool or perform a specific task; see Figure 12).



Figure 12: Tool menu that is displayed after choosing to interact with the nurse(the light blue glow around the nurse indicates to the user that they may interact with the nurse). With the tool menu, in this example, the user is able to request a particular tool from the nurse.

The surgical tools are also selected using the cursor and once a particular tool is selected, the tool appears in the hands of the user's avatar. For example, after requesting the drill, the drill appears in the surgeon's hand visible on screen (see Figure 13). Once the tool has been chosen, if the patient's knee is selected using the cursor, a menu appears providing the user a list of options corresponding to that step. For example, if the user chooses the scalpel and then clicks the patient's knee, a menu appears prompting the user to choose how big the incisions should be.



Figure 13: After choosing the scalpel, the incision can be started.

Once the correct step is chosen, a sub-game will appear prompting users to answer a multiple choice question related to the step they just completed. Answering the question correctly results in a number of "points" earned which are added to an accumulating score. If the user answers the multiple choice question incorrectly, they are corrected by an "animated angry assistant" in the form of dialogue speech (that, as described below, was voice acted and is intended to provide a "fun" factor) along with text and/or illustrations (in a pop-up window) to ensure that the user understands why their answer was incorrect (see Figure 14).



Figure 14: After completed a step, a sub-game is presented that requires the user to answer a multiple choice question. If they answer incorrectly, the correct answer with a detailed explanation is presented to the user.

If they answer the question correctly, they are presented a short video segment illustrating a surgeon performing that particular step on a "real" patient with the surgeon narrating the details of the step. If the user chooses an incorrect tool(s) for the corresponding step or performs a step out of order, they are also corrected once again by an "animated angry assistant" and are presented a text description. When the procedure is complete, the player is shown a score card listing the number of questions answered incorrectly, the number of tools selected out of order, and the overall score (as a percentage of correct responses (see Figure 15 for a sample score card)).

	MOUNT SINAI HOSPITAL
	Performance Review
	Questions answered incorrectly: 14
	Incorrect tools selected: 1
	Overall Score: 35%
and the second second	Try Again
-	Quit
-	

Figure 15: Sample score card.

3.3 GRAPHICS RENDERING SYSTEM

The 3D graphics rendering engine was developed completely "in-house" and is based on the C++ programming language and the OpenGL 3D graphics rendering API [Shreiner, 1999]. Real-time rendering is accomplished using the graphics processing unit (GPU) via the OpenGL shading language (GLSL) [Rost, 2006].

3.3.1 SHADER EFFECTS

In computer graphics, rendering is accomplished using a graphics pipeline architecture whereby rendering of objects to the display is accomplished in stages and each stage is implemented as a separate piece of hardware. The input to the pipeline is a list of vertices expressed in object space while the output is an image in the framebuffer. The stages of the pipeline and their operation are as follows [Owens et al., 2007]:

- Vertex Stage: i) Transformation of each (object space) vertex into screen space, ii) formation of triangles from the vertices, and iii) per-vertex lighting calculations.
- Rasterization Stage: i) Determination of the screen position covered by each of the triangles formed in the previous stage, and ii) interpolation of vertex parameters across the triangle.
- Fragment Stage: Calculation of the colour for each fragment output in the previous stage. Often, the colour values come from textures which are stored in texture memory. Here the appropriate texture address is generated and the corresponding value is fetched and used to compute the fragment colour.
- **Composition Stage:** Pixel values are determined from the fragments.

In contrast to the "traditional" fixed-function pipelines with "modern" (programmable) graphics processing units (GPUs), both the vertex and fragment stages are user-programmable. Programs written to control the vertex stage are known as *vertex programs* or *vertex shaders* while programs written to control the fragment stage are known as *fragment programs* or *fragment shaders*. Early on, these programs were written in assembly language. However, higher level languages have since been introduced including Microsoft's *High Level Shading*

Language (HLSL), the OpenGL Shading Language (GLSL) [Rost, 2006] and NVIDIA's Cg [Mark et al., 2003]. Generally, the input to both of these programmable stages is a four-element vector where each element represents a 32-bit floating point number. The vertex stage will output a limited number of 32bit, four element vectors while the fragment stage will output a maximum of four floating point, four element vectors that typically represent colour. The fragment stage is capable of fetching data from texture memory (memory gather), but cannot alter the address of its output which is determined before processing of the fragment begins (incapable of *memory scatter*). In contrast, within the vertex stage, the position of input vertices can be altered thus affecting where the image pixels will be drawn (i.e., the vertex stage supports both memory gather and memory scatter) [Owens et al., 2007]. In addition to vertex and fragment shaders, Shader Model 4.0 currently supported by Direct3D 10 and OpenGL 3.0, defines a new type of shader, the geometry shader. A geometry shader receives input from the vertex shader and can be used to create new geometry. It is also capable of operating on entire primitives [Sherrod, 2008].

The Metallic Effect

Environment mapping, or reflection mapping is a technique used to approximate surface reflections in real-time by means of pre-computed images instead of ray tracing the actual environment [Foley et al., 1994].

Sphere mapping (or spherical environment mapping) is a technique capable of rendering plausible reflections of the environment on objects in the scene in realtime. The environment is stored as a 2D texture depicting what a mirrored sphere would look like if it were placed in the environment [McReynolds and Blythe, 2005]. In the film industry, a reflective sphere is often photographed at various locations on a movie set. A sphere map can then be created from the photographs and used to render believable reflections for the computer-generated images (CGI), such as characters and props. The computer generated props will appear to blend in with the real objects in the scene as long as they appear to be reflecting the same environment.

Cube mapping is similar to sphere mapping in that the technique assumes that the reflected objects are very far away. A cube map consists of six square textures, one for each face of a cube. The six textures are created by rendering the environment six times. With the camera placed at the cube's center, and the sides of the cube are used as the near clipping planes for each render so that each side provides a ninety degree view. In contrast to sphere mapping, cube mapping is not viewpoint dependent, and it provides greater detail in the reflected images [McReynolds and Blythe, 2005].



Figure 16: Example of the metallic shader effect.

In this work, a sphere mapping shader is used to provide the metallic look for the tools, trays, and tables (see Figure 16). The sphere mapping shader is made computationally efficient by replacing the traditional texture coordinate calculation with an approximation. A sphere map is used as opposed to a cube map given that the greater detail provided by a cube map was not necessary. In addition, sphere maps are easier to create and modify. The sphere map texture has a range of values and is primarily grey-scale, providing the metal look to the objects it is applied to. There is a hint of beige in the lower half of the map to represent that largely beige floor. A slight blue tint in the upper half of the sphere map represents the blue blanket and clothing. The upper half of the map is very bright given that all of the lights in the operating room are close to the ceiling (see Figure 17). The metallic shader uses a normal map to allow each surface to

contain bumps and additional detail. A third texture map provides colour information as well as "baked-in" lighting such as ambient occlusion and shadows. The problem of view dependency was reduced by allowing the metallic surfaces to respond dynamically to the light sources in the room. The sphere map is then used to represent ambient environmental light only. The shader uses three textures in total: i) a texture map to provide the colour and occlusion lighting, ii) a normal map adds additional surface detail, and iii) a sphere map to represent the environment.



Figure 17: The sphere map texture used to simulate the ambient reflection of the operating room for metallic objects.

The Outer Glow Effect

Games made for entertainment often use glow effects to highlight selected objects or characters. When the player points to an object in the scene that can be interacted with, the object will appear to glow. This allows the player to directly and intuitively select objects in the 3D scene and negates the need for a separate heads-up display. The TKA serious game employs an outer glow effect whereby the outer edges of objects that the user can interact with in the game will glow when chosen by the user by moving the cursor over the corresponding object. The outer glow effect is achieved by combining three different shaders. First, the object that is to glow is rendered with a simple shader that applies a solid colour to the model ignoring lighting. This same shader is used to render other objects in the scene (that may occlude the glowing object) black (see Figure 18a).



Figure 18: (a) The scene rendered with glowing objects as solid colours. (b) Blur effect applied.

The scene is rendered with a resolution of 256×128 . Next the scene is blurred using a blur shader that blurs both horizontally and vertically in one pass (see Figure 18b). Next, all of the objects in the scene that are not glowing are rendered normally. Then the glow image is applied to the scene additively (see Figure 18a). Finally, the objects that are glowing are rendered normally (Figure 19b).



Figure 19: (a) First, the objects in the scene that are no glowing are rendered, then the glow image is added. (b) The glowing objects are then rendered over the glow image.

3.3.1 3D MODELS AND ASSETS

As part of the game, various 3D (virtual) models were developed completely "inhouse". Example models include the operating room, surgical lights, bed, nurses, surgical tools, etc. (modeled based on more than 300 photographs taken of an actual operating room at Mount Sinai Hospital in Toronto, Canada). Both lowand high-polygon count versions of these "common" models have been developed. The low polygon count models were developed using the Autodesk Maya 3D and 3Ds Max modeling and rendering software and the Pixologic Z-Brush "digital sculpting" tool. NVIDIA Mental Ray was used for "baking" and simulating the light, Headus UVLayout was used to apply UV mapping to all the models, and Xnormal was used for "baking" all the model normal maps. Figure 20 provides an example of one of the more than 300 photographs taken within the operating room at Mount Sinai hospital. Figure 21 illustrates some of the highly detailed 3D models of the surgical tools created for the TKA game.



Figure 20: Example photograph of the more than 300 photographs taken within the operating room at Mount Sinai hospital in Toronto for the purpose of 3D modelling.



Figure 21: A rendering of some of the 3D models created for the TKA serious game based on the original photographs taken in the operating room.

Models designed to be rendered interactively (in real-time) are typically constructed from a number of flat polygonal faces (see Figure 22). Polygons are connected to other neighbouring polygons at their edges to represent complex shapes. Curved surfaces are an illusion created by many small interconnected polygons. Using a high number of polygons in a model allows the shape of the model to more accurately represent a real-world object. Polygons can be rendered with images applied to them in order to increase the level of detail without increasing the number of polygons (this is known as *texture mapping* and is described in greater detail below).



Figure 22: This wire-frame image shows how the models used in the TKA game are constructed from polygons.

There is a limit to the number of polygons that can be rendered in a scene, and that limit varies depending on the hardware used to render the scene. Newer graphics cards can render a larger number of polygons, and can thus handle more complex and detailed scenes. Rendering too many polygons can cause the game to run slowly or not at all. Scenes containing too few polygons will lack detail, and edges that should be smooth will appear jagged. Therefore artists must be given a polygon budget which is based on the minimum hardware that the game is intended to be played on. The polygon budget for the TKA game was arrived at by trial and error. The game was tested at various stages using a variety of computers with differing technical specifications. A requirement for the TKA serious game was that it should be able to run smoothly (rendering at least 40 frames per second) on a typical five year old computer (at the time of this writing). Informal testing revealed that the game ran smoothly on the minimum target machine provided that the polygon count was limited to under ¼ million. Some of the models needed to be scaled back in order to meet this goal. The operating room (including the room itself, the furniture, tools, and characters) in the final version of the game contains 238,259 polygons.

Appling an image to a surface is referred to as texture mapping [Buss, 2003]. The images used are often referred to as textures because they are can be used to represent bumps and other surface irregularities, in addition to changes in colour across the surface of an object. Textures are usually designed specifically for the purpose of wrapping a 3D shape. The 2D layout of the texture is mapped to the 3D model based on coordinates (U, V) which are stored in the model along with coordinates representing the position of vertexes in 3D space (X, Y, Z). The UV layout is carefully created by the artist so that areas of the model that require
more detail are given a larger area of the texture (Figure 23 illustrates one of the textures used to add detail to one of the NPCs).



Figure 23: This texture is used to add detail to one of the character models.

3.4 INTERFACE DESIGN

The user interface was also developed taking into account the following user interface considerations [Muehl and Novak, 2008]: i) reduce screen clutter (clean,

simple layout), ii) call attention to important areas of the screen using visual and/or auditory cues, iii) concise messages, and iv) start with the basics (do not overwhelm the trainee/student with too much information from the start).

3.4.1 POP-UP MENUS

The pop-up window menus are designed to look and behave similarly to typical web pages to ensure the interface is intuitive and familiar to the majority of users. The "clickable" text appearing in the menus is blue, mimicking HTML-style hyperlinks found on typical webpages. Further mimicking typical website pages, non-clickable text within a pop-up window appears black, while clickable text changes to a lighter blue when the mouse is over it, again imitating HTML-style hyperlinks found on many webpages. Users can click on the red "X" in the top-right corner of the pop-up window to close the menu: similar to a web-browser (see Figure 14).

3.4.2 VIDEO CLIPS

Short video clips play in response to the user successfully completing each step in the procedure. The clips range in length from 17 - 71 seconds. The resolution of the video clips is 720 pixels wide by 480 pixels high and the frame rate is 29 frames per second. Each frame of video is digitally enlarged in real-time using the graphics processing unit (GPU) so that the resolution matches the resolution of the game window. The graphics engine allows shader effects to be applied to each frame of video in order to enhance the quality, or apply a stylization such as cell shading. However, these effects are currently not used in the game.



Figure 24: A screenshot taken from a video clip showing the drilling of the femoral hole.

Computer animation or cartoons can be used in place of actual surgery footage to reduce the level of gore, or to simplify the scene by leaving out details seen as unimportant. The intended audience for the total knee replacement game is surgical residents, therefore the details presented to the users needed to be as realistic as possible, and there was no need to reduce the level of gore (see Figure 24). Animations, whether they are rendered using a computer or hand drawn, are time consuming to produce. In addition, animators often fail to capture subtle details such as the flexing of muscles in the hand. When present, these subtle visual cues can tell us how much pressure the surgeon is applying for example. Such cues are best captured in video recordings of actual surgical procedures.

3.5 AUDIO SYSTEM

3.5.1 OVERVIEW

The background sound was comprised of a monaural (mono) recording made during an actual total knee replacement surgical procedure in an operating room at Mount Sinai Hospital in Toronto, Canada. Although the background sound does not include any dialogue, it does capture the typical ambient sounds present during the TKA procedure including the prominent sound of the anaesthetic machine. The background (mono) sound recordings were made using a Zoom H4n portable field recorder with a 24-bit quantization level and a 44.1 kHz sample rate.

Dialogue (speech) from the nurses and surgical assistants is included within the game. Dialogue/speech is used for output only to provide the user with feedback and an indication of how well or poorly they are doing. Dialogue is also used to increase the game's "fun factor". For example, if the surgeon asks for the incorrect tool at a particular step in the procedure, the nurse/surgical assistant may respond with the following phrases: "Are you sure that's what you want" or "Oh, that's not what we usually use next". If the user progresses through a number of steps of the procedure correctly, the nurse/surgical assistant may

respond with: "Doctor, you really are on the ball today". In addition, speech that is commonly heard throughout the knee replacement procedure is also played at various stages of the game. Several sample speech phrases are provided in Table 1. The dialogue script (phrases) was provided by the orthopaedic surgeons (content experts).

Section	Sample Line
Inquiries (calm)	"Doctor, we are prepared to begin."
Inquiries (hurried)	"We're on the clock, doctor."
Correct responses	"Check."
Incorrect responses	"This looks like a job for a different surgical instrument."
Joke (incorrect)	"Doctor, that's the wrong leg."

Table 1: Sample dialogue spoken by the nurse/surgical assistant to the surgeon/user.

Two voice actors were used for the dialogue/speech and the recordings were made in an Eckel audiometric room at UOIT (room dimensions of 2.3 m \times 2.3 m \times 2.0 m) to reduce any potential effects of environmental noises (air condition "hums", etc.) and reverberation of the generated sounds within the environment. The Eckel audiometric room provides (frequency dependent) noise reduction across a wide range of frequencies (e.g., at 19 dB at 125 Hz and 60 dB at 4 kHz). Dialogue was recorded using Digidesign's Pro Tools LE v 7.1 (with a 24-bit quantization level, and a 44.1 kHz sample rate) and an Apex 415 studio

condenser microphone (omni-directional polar pattern). All sounds are rendered using the FMOD music and sound effects system.

3.5.2 SPATIAL SOUND SYSTEM

In our natural surroundings we hear sounds from different locations, at different distances and after they have interacted with a variety of objects. We are capable of distinguishing individual sounds by pitch, tone, loudness, and by their location in space. Our ability to extract spatial information from the sounds we hear provides us with detailed information about our surroundings, assisting us in determining both the distance to and the direction of objects [Warren, 1983]. Furthermore, hearing serves to guide our more finely tuned visual attention system, thereby easing the burden on the visual system [Cohen and Wenzel, 1995]. The spatial sounds which are present in our environment provide us with detailed information gur surroundings and are at times are crucial to our survival.

Three dimensional (spatial) sound allows a listener to perceive the position of sound sources, emanating from a static number of stationary loudspeakers or a pair of headphones, as coming from arbitrary locations in three dimensional space [Kapralos et al., 2008]. Spatial sound technology goes far beyond traditional stereo and surround sound techniques by allowing a virtual sound source to have such attributes as left-right, back-forth and up-down [Cohen and Wenzel, 1995]. The foundation of spatial sound rests on the ability to control the auditory signals arriving at the listener's ears such that these signals are

perceptually equivalent to the signals that the listener would receive in the environment being simulated [Ward and Elko, 2000]. In contrast to the visual sense, hearing is omni-directional, and therefore, sound within a game provides the capability of a 360° field of interaction using spatial sound techniques. However, despite the benefits of spatial sound, its generation is not a trivial matter. This is particularly so when considering the reconstruction of a listening environment by physical or mathematical modeling means, taking into account the acoustics of the environment and the characteristics of the listener. To recreate a sound in a three-dimensional space, sound source material must be filtered with the appropriate head-related transfer function (or HRTF which the distance- and direction- dependent filtering effects of a sound reaching a listener due to the listener's head, shoulders, upper-torso, and most notably, the pinna of each ear) and room impulse response (or RIR, which captures the reflection properties, diffraction, refraction, sound attenuation and absorption properties of a particular room configuration i.e., the "room acoustics") dynamically to account for listener and sound source movements, in real-time. Filtering is accomplished by a convolution operation. However, convolution is a computationally expensive operation especially when considering the long filters associated with HRTFs and RIRs (filters with 512 coefficients are not uncommon) thus limiting their use to non-real-time applications (a detailed discussion of spatial sound is available in [Kapralos et al., 2008]).

Given the importance of spatial hearing to humans, incorporating spatialized sound cues in realistic simulations such as immersive virtual environments including serious games seems obvious. In fact, doing so can be beneficial for a variety of reasons. Spatial sound cues can add a better sense of "presence" or "immersion", they can compensate for poor visual cues (graphics), lead to improved object localization and, at the very least, add a "pleasing quality" to the simulation [Shilling and Shinn-Cunningham, 2002].

Although the inclusion of such sounds can lead to greater realism and quality, spatial sound cues are often overlooked by the majority of immersive virtual environments and video games, where emphasis has historically been placed on the visual senses instead [Doel et al., 2001; Cohen, and Wenzel, 1995]. Furthermore, when present, the spatial sound cues in these systems do not necessarily reflect natural cues, typically assuming that all interactions (reflections) between a sound wave and objects/surfaces in the environment are specular. That is despite the fact that in our natural settings, acoustical reflections may be diffuse and there may also be diffractive and refracted components as well. In fact, since the dimensions of many of the objects/surfaces encountered in our daily lives is within the same order of magnitude as the wavelength of audible sounds, diffraction, or the "bending mode" of sound propagation whereby sound waves go ("bend") around an obstacle that lies directly in the line of straight propagation, is an elementary

means of sound propagation especially when there is no direct path between the sound source and the receiver, such as in buildings [Tsingos et al., 2001].

Existing systems which attempt to model these non-specular reflection phenomena do so poorly, yet failure to accurately model all these phenomena leads to a decrease in the spatialization capabilities of the system, ultimately leading to a decrease in performance and a decrease in presence or immersion [Svensson and Kristiansen, 2002].

Given the importance and benefits of spatial sound within a virtual environment, the TKA serious game supports the rendering of spatial sound which includes the modeling/rendering reverberation and occlusion/diffraction effects using novel GPU-based methods that approximate such effects at interactive rates [Cowan and Kapralos, 2010, 2011a]. The system also supports head-related transfer functions (HRTFs) and HRTF filtering is accomplished using GPU-based convolution ensuring interactive frame-rates [Cowan and Kapralos, 2008, 2009]. Spatial sound by default is not activated; it is an option that can be chosen during start-up. By default, sounds are non-spatialized and output in a traditional stereo format. Greater details regarding the occlusion and reverberation effects are provided below. Detailed implementation details of the GPU-based spatial sound methods and techniques developed specifically for this work appear in a number of refereed journal articles by the author (see [Cowan and Kapralos, 2008, 2009, 2010, 2011a,b]) and will therefore not be repeated here.

3.6 SURGICAL COGNITIVE EDUCATION AND TRAINING FRAMEWORK

The knee replacement serious game described above has generally been well received by medical experts and surgeons. This has led to various discussions regarding the development of additional serious games for surgical procedure education and training for a number of procedures. Given the potential for the development of additional serious games for other surgical procedures, it was decided that a serious games framework that, through the re-use of common elements (e.g., audio and visual rendering, operating room models, etc.), will allow for the efficient development of serious games that focus on the cognitive aspects of a particular surgical procedure (i.e., the steps comprising the procedure, the tools required at each step, and the capability of responding and adapting to the wide range of contextual variations that may require adjustments to the standard approach). As previously described, this has led to the development of a multi-modal, serious game surgical cognitive education and training framework (SCETF). Domain-specific surgical "modules" can then be built on top of the existing framework, utilizing common simulation elements/assets and ultimately reducing development costs. The SCETF focus is on the cognitive aspects of a surgical procedure described above. By clearly understanding the steps of a procedure and the surgical knowledge that goes along with each step, trainees are able to focus solely on the technical aspect of the procedure (i.e., the actual execution) in higher fidelity models or in the

operating room thus making more efficient use of the limited available resources. The SCETF is also being developed as a research tool where various simulation parameters (e.g., levels of audio/visual fidelity) can be easily adjusted allowing for the controlled testing of such factors on knowledge transfer and retention and this will ultimately lead to more effective serious games.

3.5.1 SCETF TECHNICAL DETAILS

The SCETF consists of graphical and spatial sound rendering engines in addition to other components that are common (generic) to all serious games. The graphics and audio rendering system builds upon the graphics and audio rendering capabilities of the TKA game described above. A "scenario" editor (currently being developed) will allows users of the module (educators/instructors) to create and/or modify/edit specific scenarios using a graphical-based user interface. The scenario editor will allow, a scenario to be easily developed by "clicking and dragging" various interface components.

As with the TKA serious game, the modules developed for the SCETF will allow trainees to take on the role of the surgeon, viewing the environment through their avatar in a first-person perspective and as such only their hand is visible. Several other non-player characters (NPCs) also appear in the scene including the patient (lying on a bed), assistants, and nurses. The SCETF includes networking capabilities to allow these NPCs to be controlled by other users and provide an entire surgical team the opportunity to practice remotely and allow for

interprofessional education. The trainee (user) can move and rotate the "camera" using the mouse in a first-person manner thus allowing them to move within the scene. A cursor appears on the screen and the trainee can use this cursor to point at specific objects and locations in the scene. The task of the trainee is to complete the surgical procedure following the appropriate steps and choosing the correct tools for each step. Along the way, complications can arise which will require some action from the trainee. These complications will appear in the form of visual or auditory cues adapted according to predefined features of the simulated surgical scenario.

Currently, the SCETF supports the alteration of audio and visual fidelity and the interaction of audio and visual cues particularly if they are incongruent and mismatched (i.e., high quality audio and poor quality visuals and vice-versa). With respect to audio fidelity currently, the following options are supported: i) spatial sound vs. non-spatial sound, ii) no audio (background sound and/or all sound effects can be turned off), iii) adjustable quantization levels, iv) addition of white noise to background sounds and/or sound effects, and v) adjustment of loudness and dynamic range. Such effects (and their corresponding settings) are chosen during start-up and cannot be adjusted dynamically. Visual (graphical) fidelity ranges from high to low quality, defined with respect to polygon count, and resolution (both texture resolution and overall resolution). These particular fidelity measures cannot be adjusted dynamically but rather, their settings must be specified during an initialization phase at start-up. The SCETF also provides

for the dynamic adjustment visual fidelity through various graphical filtering effects implemented using the graphics processing unit (GPU). The degree of filtering introduced by each of these effects can be dynamically adjusted via a "slider control" and these effects can also be combined dynamically. For example, the scene can be blurred using the blurring filter and noise can also be added with the noise filer. An example of these effects is provided in Figure 25 where the results of applying each of these filters (individually) to the original scene of Figure 25(a) are shown in Figures 25(b)-(h) respectively.



Figure 25: Examples of the filtering effects that are available to alter visual fidelity. The degree of filtering for each of the effects is adjustable (dynamically) via a scroll-bar available on the graphical user interface. All effects are implemented with the GPU and are applied dynamically at interactive rates.

4. EXPERIMENTS AND RESULTS

4.1 TKA GAME USABILITY STUDY

As previously described, the serious game was developed using an "iterative test-and-design" methodology whereby the final implementation accounted for the feedback from orthopaedic surgery residents and game development students obtained via a usability study (institutional ethics approval was obtained for this study). Usability studies were carried out in a focus group setting whereby the participants were provided a brief (five-minute) overview of the serious game (purpose, how to use it, etc.), followed by a 30 minute exploratory period that involved using the serious game and freely exploring its interface/options. Finally, participants were asked to complete a brief questionnaire which comprised a subset of questions (32) from the Questionnaire for User Interaction Satisfaction (QUIS) [Shneiderman, 1998]. QUIS is a tool developed by a multi-disciplinary team at the University of Maryland. It was designed to assess users' subjective satisfaction with specific aspects of the human-computer interface and is considered highly reliable across many types of interfaces. [Shneiderman, 1998]. The questions measure the users' overall satisfaction with some aspect of the interface and the factors that make up that facet on a 9-point Likert scale. Each question is in the form of a statement [QUIS, 2012]. Participants are asked to rate their level of agreement with each statement. QUIS can be customized to suit a specific type of interface by omitting the questions and sections that are not relevant. In addition to the QUIS-based questions, the questionnaire contained several "open-ended" questions were participants were asked for any

comments/suggestions regarding the serious game and more specifically, its graphical user interface.

4.1.1 PARTICIPANTS

The participants were comprised of eleven unpaid students, seven from the Game Development program at the University of Ontario Institute of Technology, and four orthopaedic surgery residents from the Department of Surgery, University of Toronto. Two separate sessions were held: one session for the game development students and the other for the orthopaedic surgery residents. In total, each focus group session lasted approximately one hour. A small sample size was employed in order to perform an "initial assessment" test to detect and correct the majority of usability issues (if any) early in the design phase prior to the final serious game implementation (i.e., to allow for an "iterative test-and-design" manner) [Turner et al., 2006; Virzi, 1992]. This study abided by the UOIT Research Ethics Review process.

4.1.2 THE FOCUS GROUP STUDY

The following features were highlighted by the participants as necessary in order to enhance realism, navigation, immersion, and educational benefit and have been taken into account in the current implementation stage:

- Provide various alternatives for moving objects (e.g., both mouse, and 'W,A,S,D' keys).
- 2. Rendering effects are very important.

- Incorporate videos of some of the procedure tasks as a source of information.
- 4. Incorporate audio/sound cues while performing the tasks.
- 5. Allow users to select the level of difficulty for a given task.
- 6. Provide training strategies on the features and use of the game such as an instructional webpage or educational workshops.
- 7. Lack of time is a potential threat to using such types of games.

The 32 QUIS-based questions were classified into four categories:

- 1. Overall reactions to the system.
- 2. Graphics and sound.
- 3. Learning.
- 4. System capabilities.

A summary of the results appears in the bar graphs of Figures 26 to 29 where, for each question in each category, the number of responses from each of the 10 choices (1-9 in addition to NA or non-applicable) is shown (colour coded). The results from Category 1 are shown in Figure 26. The majority of participants believed that the serious game is good, were satisfied with it, and believed that it was adequately stimulating and easy to use.



Figure 26: Results: overall reactions to the system.

Category 2 results are shown in Figure 27. The majority of participants indicated that the serious game has good graphics; found the highlighting feature (used to indicate a "clickable" object) to be useful, and found that the amount of information provided is adequate and logically arranged on the screen.

Category 3 results are shown in Figure 28. The majority of participants indicated that the serious game is adequate with respect to allowing them to learn how to operate it, to learn advanced features, to explore and discover new features, and to remember previously used commands. Moreover, participants believed that the serious game is properly designed to provide a logical sequence to complete tasks and that it provides feedback on the completion of particular steps.

The results from Category 4 are shown in Figure 29. The majority of participants indicated that the system was fast enough with respect to response time for most operations and the display of information. They also indicated that the serious game was adequately reliable, that failures rarely occurred, that it provided them

the opportunity to correct mistakes, that it provided the ability to undo operations, and that it adjusted to the user's prior experience level.



Graphics and Sounds. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.

Graphics and Sounds. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.



Figure 27: Results: graphics and sound.

Learning. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.



Learning. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.



Learning. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.



Figure 28: Results: learning.



System Capabilities. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.

System Capabilities. Select the number which most appropriately reflect your impressions of using the software or system. Not Applicable = NA.



Figure 29: Results: system capabilities.

4.2 MULTIMODAL INTERACTIONS

As previously described, the SCETF is being developed as a research tool to enable the investigation of the effect of multimodal cue interaction on knowledge transfer and retention. Using the SCETF as a research tool, the following study was conducted to examine the effect of ambient sound on the perception of visual fidelity and the time required to complete a simple task within a virtual environment (i.e., the task completion time). Participants were asked to complete a simple task under differing auditory and visual conditions. The results of this study bring us closer to developing an understanding of the role that fidelity, and multi-modal interactions play with respect to knowledge transfer and retention for users of virtual simulations and serious games.

4.2.1 VISUAL STIMULI

The visual scene consisted of six rendered (3D) versions of an operating room with various tools, and equipment. Within the operating room were three nonplayer characters (nurses) which, for the purposes of this experiment, remained static and did not afford any interaction with the participants. Each of the rendered versions of the scene was filtered (dynamically) with a blurring filter which caused the scene to be blurred. The level of blurring introduced to each of the six scenes varied linearly from 0 to 1 with 0 (no blurring introduced; i.e., the original, reference scene), and 1 (the highest level of blurring). The blurring effect was accomplished dynamically using an OpenGL GLSL-based shader. The blurring was accomplished by (on a per-pixel basis) sampling several discrete areas around a center point (each pixel) and averaging the result. An example of the six levels of blurring is provided in Figure 30.



Figure 30: The levels of visual fidelity (defined with respect to image blurring) considered in this experiment. (a) Original (non-filtered) version. (b) – (f) Application of the blurring filter with an increase in the blurring effect as the image labels are incremented from (b) – (f).

4.2.2 AUDITORY STIMULI

Four ambient (background sound) conditions were examined and with respect to the visual scene, they were classified as either non-contextual sounds: i) no sound, ii) white noise, or contextual sounds: iii) operating room ambiance mixed with a surgical drill sound, and iv) operating room ambiance without the drill sound. The operating room ambiance sound included machines beeping, doctors and nurses talking, and was purchased from AudioSparx.com and the operating room ambiance with the drill sound was made by mixing the operating room ambiance sound with a recording of an actual drill sound (it was mixed using the Audacity audio editor software). The recording was made in an Eckel audiometric room to limit any external noise (air condition "hums", etc.) and reverberation of the generated sounds within the environment, at a sampling rate of 44.1 kHz. The white noise sound was sampled at a rate of 44.1 kHz and band-pass filtered using a 256-point Hamming windowed FIR filter with low and high frequency cut-offs of 200 Hz and 10 kHz respectively.

The level of each of the three sounds was normalized (using the "normalize multiple audio tracks" option of the Audacity audio editor software) to ensure that all three sounds (tracks) had the same peak level. For all trials, the auditory stimulus (when present) began playing at the start of the trial and was stopped once the participant chose the surgical drill from the tray of surgical instruments. The sound pressure level of the output sounds was 66dB (about the same level as typical conversation [Morfey, 2001]), measured with a Radio Shack sound level meter (model 33-2055). All auditory stimuli were monophonic and were output with a pair of Sony MDR 110LP headphones.

4.2.3 EXPERIMENTAL METHOD

Participants were seated in front of a laptop computer which was used to conduct the experiment. Participants were provided with an overview of the experiment followed by a description of their required task by one of the experimenters. In each trial, participants were presented with one of the six versions of the rendered operating room shown in Figure 30, in conjunction with one of the four ambient sound conditions previously described. Their task was to navigate through the operating room from their starting position (see Figure 31(a)) to a point in the room which contained a tray with surgical instruments and pick up a surgical drill (they had to navigate around the bed and one of the NPC nurses to reach the tray that contained the surgical instruments).



Figure 31: The experimental environment. (a) Then view of the operating room environment at the start of each experimental trial. The task of each participant was to navigate the environment from the starting position to the position of the surgical drill and then "choosing" the drill. (b) Upon choosing the drill, participants were prompted to rank their perception of the visual quality.

Navigation through the environment was accomplished in a first-person perspective (taking on the role of the surgeon) using the standard arrow keys (to move the "player") and mouse (to move the "camera"). Within this first-person view, the hand and lower arm of the participant's avatar was displayed. Choosing the surgical drill involved moving their avatar's hand over the drill and clicking the left mouse button. Once the drill was chosen, it appeared in the hand of the user's avatar and the participant was prompted to rank the visual scene with respect to their perceived visual quality on a scale from 1 (lowest perceived quality), to 7 (highest perceived quality); see Figure 31(b). Aside from interacting with the surgical instruments, there were no other interactions permitted (e.g., the participants could not interact with any of the NPCs or other objects in the room). Entering their choice signalled the end of the trial; the following trial began after the user clicked the "Continue" button that appeared on the visual quality ranking screen after the participant entered their choice. Each of the six rendered versions of the operating room and each of the four ambient sound combinations (24 combinations in total) was repeated three times for a total of 72 trials, all of which were presented in a randomized ordering. The experiment took approximately 30 minutes to complete and all participants completed it in a single session. Finally, the experiment was carried out on an Acer Aspire laptop with a 15.6" screen size and a screen resolution of 1366 × 768. The operating room environment was viewed in "full screen" mode.

4.2.4 EXPERIMENTAL RESULTS

Two different variables were analyzed as outcomes for this experiment. The first one was the participants' perceived quality of the visual scene in the presence various ambient auditory cues and the second was the total task completion time. Results of the first analysis (perceived visual quality) are summarized in Figure 32 where the x-axis represents visual quality (amount of visual blurring) and the y-axis represents perceived quality (ranging from 1-7). A summary of the visual quality perception averaged across each of the four auditory conditions for each of the blurring levels is provided in Table 2. Inspection of Figure 32 and Table 2 clearly indicate that visual quality perception decreases as the level of blurriness increases.



Figure 32: Experimental results. Visual quality perception (x-axis) vs. image blurring level under four ambient sound conditions. Image fidelity is defined with respect to a blurring of the entire scene with Level 1 representing the least blurring and level 6 the greatest blurring.

Blurring Level	Visual Quality (/7.00) ± Std. Dev.
1	6.66 ± 0.23
2	5.54 ± 0.20
3	4.15 ± 0.22
4	3.04 ± 0.16
5	2.38 ± 0.17
6	1.81 ± 0.13

Table 2: Visual quality perception averaged across blurring level.

The analysis of variance (ANOVA) was selected as the statistical model with two factors: 6 visual conditions × 4 ambient (background) auditory conditions. Main effects and interactions were further analyzed using the Tukey HSD post-hoc comparisons. In addition to the main effects for visual conditions (p<.000) and ambient sound (p<.130), there was no significant interaction between the ambient sound and image (p<1.00). Post-hoc tests revealed that the type of ambient sound did not influence the perceived quality of the visual scene irrespective of the level of blurring. Although there was no difference in visual quality perception with respect to auditory conditions, there was a significant difference between the each of the six visual conditions examined. In other words, participants did perceive a difference in visual quality across each of the six scenes that they were presented with.

The second variable analyzed was the task completion time (i.e., the time taken for the participant to reach the tray with the surgical instruments and "choose" the drill, from the initial starting point). Results of the second variable analyzed (task completion time) are summarized in Figure 33 where the x-axis represents the ambient sound condition and the y-axis represents time (in seconds). A summary of the task completion time averaged across each of the six visual fidelity conditions for each of auditory conditions is provided in Table 3.



Ambeint (Background) Sound Condition

Figure 33: Experimental results. Ambient auditory condition (x-axis) vs. time to complete the task (y-axis).

Ambient Sound Condition	Time (s) ± Std. Dev. (s)
No sound	7.30 ± 0.41
White noise	9.26 ± 0.44
Operating room ambiance with drill sound	6.97 ± 0.32
Operating room ambiance	5.71 ± 0.13

Table 3: Task completion time averaged across auditory condition.

The analysis of variance (ANOVA) was selected again as the statistical model with two factors: 6 visual conditions \times 4 ambient (background) sounds. Main effects and interactions were further analyzed using Tukey HSD post-hoc comparisons. Furthermore from the main effects for visual conditions (p<.902) and ambient sound (p<.000), there was no significant interaction between the sound and image (p<.936). Post-hoc tests revealed that the type of ambient sound influenced the task completion time. The auditory condition consisting of white noise sound resulted in the largest task completion times while the auditory condition consisting of the operating room ambiance alone resulted in the least amount of time to complete the task. Interestingly, the auditory condition consisting of the operating room ambiance with the drill sound showed a similar effect (with respect to task completion time) to the no-sound condition, both of which resulted in task completion times that were greater than task completion times of the operating room ambiance auditory.

5. DISCUSSION

5.1 USABILITY STUDY RESULTS

In this thesis, a serious game for total knee arthroplasty (replacement) surgery was presented for the purpose of educating and training orthopaedic surgery residents the cognitive aspects of the procedure (i.e., the series of steps comprising the procedure in addition to the tools required for each step). A preliminary usability study was conducted with four unpaid orthopaedic surgery residents from the Department of Surgery at the University of Toronto (Toronto, Canada) and seven unpaid senior students from the Game Development and Entrepreneurship program at the University of Ontario Institute of Technology (Oshawa, Canada). The purpose of the usability study was two-fold: i) to perform an "initial assessment test" of the serious game, and ii) to obtain and incorporate any comments regarding the serious game and more specifically, the user interface into the final implementation. As the results confirm, the TKA serious game is easy to use, intuitive, and stimulating.

Despite the small number of participants (11), previous influential studies that have investigated sample size with respect to usability studies have revealed that the majority of usability problems are detected with the first three to five participants and more importantly, when including additional participants within the same study it is unlikely any new information will be revealed [Lewis, 1994; Nielson and Landaurers, 1993; Turner et al., 2006; Virzi, 1992]. Virzi, [1992] claims that running usability tests using small samples in an iterative test-and-

design fashion will identify most usability problems and leads to both time and money savings. This claim is based on the outcome of a series of earlier experiments conducted by Virzi [1992]: i) observing four or five participants allows practitioners to discover 80% of a product's usability problems, (ii) observing additional participants reveals fewer and fewer new usability problems, and (iii) the more severe usability problems are detected by the first few participants.

The 32 QUIS-based questions were classified into four categories: i) overall reactions to the system, ii) graphics and sound, iii) learning, and iv) system capabilities. The majority of participants found the TKA game to be stimulating and easy to use. Participants indicated that the game had good graphics, and that the interface was logically arranged on the screen. In addition, the majority of participants also indicated that the game's interface was intuitive and properly designed. Adequate feedback was given in response to incorrect answers providing users with the opportunity to correct mistakes. It should be noted that although the usability results are positive and encouraging, the results only pertain to the interface and user perceptions of the game and not to the effectiveness of the serious game. The effectiveness of the serious game is being examined in a series of studies led by orthopaedic surgeons Dr. David Backstein and Dr. Mark Porte from Mount Sinai Hospital (Toronto, Canada). The studies involve novice, intermediate, and advanced orthopaedic surgery residents from the Department of Surgery at the University of Toronto (Toronto,

Canada) and is based on pre- and post-testing, a common approach in educational research [Becker and Parker, 2011]. With a pre- and post- testing design, participants are randomly allocated to either a "treatment" group or a "control" group. Both groups receive an identical pre-test (ensures that the groups are equivalent) and then each group receives a different "treatment": either the intervention being examined (playing the serious game), or the "usual treatment" (don't play the serious game but rather rely solely on traditional instructional approaches). Upon completion of the "treatment" (experiment), both groups are given (the same) post-test and the results of the pre- and post-tests are compared across both groups. Differences in the scores across the groups are assumed to be a result of the "treatment" (the serious game). Testing was recently completed and results are currently being analyzed.

5.1.1 KNOWEDGE TRANSLATION

The recent translation trend of research-derived knowledge into actual practice, implies that some thought should be given by researchers regarding the knowledge (i.e., research product) that should be put into practice and to which audience it should be directed, keeping in mind how the knowledge could be used [Tetroe, 2007]. This process is called 'knowledge translation' (KT) and the strategies designed by researchers to provide a match between the expected research findings and the targeted knowledge-user(s) are referred to as KT plans [Ross, et al., 2007]. In following this trend, it was decided to provide a KT structure to the development and testing of the serious game described in this

thesis. Although the impact of the KT approach can only be assessed once the TKA serious game has been formally "field-tested", it is anticipated that a strategy to increase the KT effectiveness is to engage the potential end-users (e.g., the orthopaedic surgery residents) early in the design and implementation of the game.

In terms of the overall KT plan that we are concurrently being formulating, the main issues to be addressed will be: i) persuading end-users that a serious game is an effective learning tool, and ii) assisting them in integrating the serious game within their training activities. Consequently, as part of our future work, we will also conduct a usability survey with a larger pool of end-users will be conducted in order to both gauge their perceptions on the final version of the game and to refine the knowledge translation strategies that should be implemented during the educational encounter. Amongst them, the possibility of implementing faceto-face interactive workshops, as well as creating an online community of practice, which have been identified in the literature as some of the most effective KT methods [Grol and Grimshaw, 2003] are being considered. The feasibility of the KT plan will be tested in future work by conducting studies to test the effectiveness of using a serious game as a complement to traditional teaching materials to train orthopaedic surgery residents in total knee arthroplasty.

5.2 MULTI-MODAL INTERACTION STUDY RESULTS

Preliminary details of the serious game surgical cognitive education and training framework (SCETF) that is currently being developed for cognitive surgical skills training were presented in Chapter Three. Using the SCETF, an experiment was conducted that examined the effect of contextual ambient (background) sound on visual fidelity perception (defined with respect blurring of the scene), and task completion time while conducting a simple task (navigating through a virtual operating room to reach a tray of surgical instruments) was examined. Results indicate that ambient (background) sound has no influence on the perception of visual quality irrespective of the level of blurring or whether the auditory cues were contextual or non-contextual with respect to the visual scene. However, results also indicated that ambient sound did have an effect on task completion time and more specifically, white noise led to a large increase in task completion time while contextual ambient sound consisting of operating room ambiance resulted in the lowest task completion time.

Previous work revealed that the perception of visual quality of a virtual model is dependent on ambient (background) sound [Rojas, et al., 2011; Rojas, et al., 2012]. Previous work examined perception of visual fidelity perception of a single object (a surgeon's head) with visual fidelity defined with respect to polygon count [Rojas, et al., 2011], and texture resolution [Rojas, et al., 2012], in the presence of various ambient auditory conditions (that were non-contextual with respect to the visual scene) including white noise, classical music, and heavy

metal music. In those studies, it was observed that auditory cues did in fact influence the perception of visual fidelity (white noise resulted in a decrease of visual fidelity perception [Rojas, et al., 2012], and classical music increased perception of visual quality for visual fidelity defined with respect to polygon count, particularly for the images corresponding to the highest polygon counts. Further evidence regarding the effect of ambient sound on other modalities is also available from various "real-world" studies. For example, Woods, et al., [2011] discovered that background sound (noise) can have an effect on the perception of food gustatory properties (i.e., sugar level, salt level), food crunchiness and food liking. They found that background noise has three effects on food perception: i) food saltiness and sweetness was reduced in the presence of loud background noise, ii) food was "crunchier" in the presence of background noise, and iii) there was a correlation between the liking of the food and the liking of the noise. Although here ambient sound did not have any effect on visual quality perception, with respect to previous work, there were several important differences.

Here, both contextual and non-contextual ambient auditory cues (with respect to the visual scene) were considered. Furthermore, the visual scene was modeled after an actual operating room and contained many objects (the operating room itself, the bed, lights, NPCs, etc.) as opposed to a single model considered in previous work [Rojas, et al., 2011, 2012]. Also, here visual quality was defined with respect to blurring of the scene which was chosen to approximate the effect
of reduced texture resolution as in [Rojas, et al., 2012] (in the study presented here, there were far too many objects/models making it impractical to individually reduce the texture resolutions of each). In addition, here participants were required to complete a task (navigate the operating room to reach the surgical drill) and this may have led to overloading the system and differential effects of sensory manipulations on perception and action. As speculated by Milner and Goodale [1995] and their two-stream hypothesis of visual processing, visual information is processed in different areas of the brain when the intention of the visual information is to make a judgment (the ventral stream) or to make an action (the dorsal stream).

Although ambient sound did not affect visual fidelity perception, it did have an effect on the total time required to complete the task ("task completion time") and more specifically, ambient sound consisting of white noise sound resulted in the largest task completion times while the operating room ambiance sound resulted the lowest task completion time. Interestingly, the ambient sound condition consisting of the operating room ambiance with drill sound showed a similar effect (with respect to completion time) to the no-sound condition, both of which were greater than the auditory condition consisting of the operating room ambiance only. This result is supported by previous work. Conrad, et al. [2010] examined the effect of background sound (including classical music (Mozart), and heavy metal music to induce "auditory stress") on laparoscopic surgery. They found that stressful music (e.g., heavy metal) had a negative impact on task

completion time but did not impact task accuracy. They also found that classical music had a variable effect on time until task completion but resulted in greater task accuracy amongst all participants (laparoscopic surgeons). Although task accuracy was not examined here, it has been shown that ambient sound consisting of white noise has a negative impact on task completion time similar to the "stressful" music of the Conrad, et al. [2010] study.

Collectively, the results presented here and in previous work, suggest that sound can affect various aspects of a virtual simulation/serious game. Distracting sounds such as white noise can not only decrease the perception of visual fidelity, but can detrimentally affect task completion time. Designers and developers of virtual simulations and serious games should work closely with educators and content experts to explore and devise proper ways to help trainees in learning how to perform under the presence of potentially distracting sounds which, in many situations, characterize the real-world environment. Perhaps virtual simulations and serious games can be used to explicitly acquaint trainees with such "real-world" distracting sounds while performing technical tasks to minimize any negative effects when distracting sounds are encountered in the real-world.

6. CONCLUSIONS

Total knee arthroplasty (TKA) is a commonly performed surgical procedure whereby knee joint surfaces are replaced with metal and polyethelene components that serve to function in the way that bone and cartilage previously had. Surgical training has predominantly taken place in operating rooms, placing a drain on the limited available operating room resources. Simulations, both physical and virtual, have been effectively used to complement residents' training and education. In addition to promoting learning via interaction, serious games allow users to experience situations that are difficult (even impossible) to achieve in reality and they support the development of various skills including analytical and spatial, strategic, recollection, and psychomotor skills as well as visual selective attention. In this thesis, a serious game that was designed using an "iterative test-and-design" manner for the purpose of training orthopaedic surgery residents the series of steps comprising the total knee arthroplasty (TKA) (also known as total knee replacement) surgical procedure was presented. Real-time, 3D graphical and sound rendering technologies are employed to provide sensory realism consistent with the real-world ensuring that the knowledge gained within the serious game can be easily recalled and applied when the trainee is placed in the real world scenario.

A usability study was conducted to perform an "initial assessment test" of the TKA serious game for the purpose of incorporating user feedback into the final implementation. The majority of participants indicated that the interface was

intuitive. Moreover, participants believed that the TKA serious game was properly designed to provide a logical sequence to complete tasks and that it provides feedback on the completion of particular steps. The majority of participants indicated that the system was fast enough with respect to response time for most operations and the display of information. They also indicated that the serious game was adequately reliable, that it provided them the opportunity to correct mistakes they might have made, that it provided the ability to undo operations, and that it adjusted to the user's prior experience level.

The positive feedback of the TKA serious game and the interest by a various medical experts and surgeons to develop similar serious games for other surgical procedures has started the development of a multi-modal, *serious game surgical cognitive education and training framework* (SCETF). The SCETF focus is on the cognitive components of a surgical procedure and more specifically, the steps comprising a particular surgical procedure, the anatomical and physiological knowledge, and the tools/equipment required at each step/stage of the procedure. In addition to its use for surgical procedure training, the SCETF is being developed as a research tool to enable the investigation of the effect of multimodal cue interaction, and audio-visual levels of fidelity on knowledge transfer and retention. A preliminary experiment using the SCETF and a modified version of the TKA serious game was conducted to examine the effect of ambient (background) sound on visual fidelity perception and task completion time while conducting a simple task was examined. Results indicate that ambient

(background) sound has no influence on the perception of visual quality but it was observed that ambient sound does influence task completion time.

Collectively, the results of this preliminary study and the results of previous work, suggest that sound can affect various aspects of a virtual simulation/serious game. Distracting sounds such as white noise can not only decrease the perception of visual fidelity, but can detrimentally affect task completion time. Designers and developers of virtual simulations and serious games should work closely with educators and content experts to explore and devise proper ways to help trainees in learning how to perform under the presence of potentially distracting sounds which, in many situations, characterize the real-world environment and cannot be eliminated. Perhaps virtual simulations and serious games can be used to explicitly acquaint trainees with such "real-world" distracting sounds while performing technical tasks to minimize any negative effects when distracting sounds are encountered in the real-world.

6.1 CONTRIBUTIONS

This thesis describes the development of a serious game for total knee arthroplasty (TKA) (replacement) education and training. There were a number of constraints imposed by the content experts, by the technology, and by the skill set of the intended audience. A preliminary usability study conducted with orthopaedic surgery residents and game development students indicates that the TKA game is intuitive, easy to use, and informative.

The serious game surgical cognitive education and training framework (SCETF) was developed to allow for the development of similar serious games by re-using common elements/assets thus reducing development time and costs. A preliminary version of the SCETF was used to conduct a study to examine the effect of sound on visual fidelity perception and task completion time while performing a simple task within a virtual environment. The results revealed that although background sound did not have any effect on visual fidelity, background sound consisting of white noise had a negative effect on the time required to complete a simple task within a virtual environment.

6.2 FUTURE WORK

In addition to testing the effectiveness of the serious game as an educational aid through the use of pre- and post-testing with orthopaedic surgery residents, from a technological perspective, future work will also investigate the factors that will lead to a maximum transfer of knowledge and retention for users of games for learning and training with respect to game parameters. This will include examining i) do "better", more realistic graphical and sound cues lead to greater transfer of knowledge, and ii) how do multi-cues (graphical and auditory cues in particular) interact and affect the transfer of knowledge? Given very realistic, high quality models, lower quality models can easily be derived. This provides the opportunity to develop various versions of the serious game (with respect to visual/graphics based quality) and examine how levels of realism affect transfer of knowledge. Future work will also include incorporating artificial intelligence (AI)

techniques and pre-defined motions into the non-playing characters (NPCs) providing them with more realistic behaviours. In a team setting where players may be logged in from diverse locations, it would be useful to have artificially intelligent agents who could fill in for human participants. Human players may need to stop playing before the scenario has finished, and players could be disconnected at any time due to loss of internet connectivity. Computer controlled characters could allow the remaining players to complete the scenario uninterrupted.

APPENDIX I – TKA SERIOUS GAME INSTRUCTIONS

The following information is included with the game as a one page PDF file.

A Serious Game for Knee Replacement Surgery Procedure Training

Software Requirements

This version of the knee replacement surgery game is designed for the Windows operating system and requires a graphics card with support for the OpenGL shading language (GLSL). Up-to-date video codecs are also required.

Installation

From a Zipped File: Unzip the entire contents of the folder to a folder located on your hard drive. Double-click on the file named "KneeSurgery.exe".

From a CD: The game can be played directly from the CD, although the game might load and run faster from your hard drive. Simply copy all of the files from the CD to a folder on your hard drive.

How to Play

The player can move around the operating room using the arrow keys and mouse. Move the mouse to look around the room. If you point at an object in the scene that is interactive, the object will appear to glow. Left click on the nurse, tool tray, or patient to bring up a menu. The menus are designed to behave like web-pages. The blue text can be clicked on to open a new page or perform an action. Video clips are played at various stages in the procedure (they may be skipped by pressing the SPACE bar).

Controls

Move the mouse to rotate the camera or to move the mouse pointer while a popup window is displayed. Use the left mouse button to click on objects in the scene or blue text in the menus. The arrow keys can be used to move around the room, but it is not required. Press Esc to exit the game at any time. Press the SPACE bar to skip playback of the surgery clips.

Disclaimer

This is free software and must not be sold commercially. This software is provided "as-is," without any express or implied warranty. In no event shall the author be held liable for any damages arising from the use of this software.

APPENDIX II – USABILITY STUDY QUESTIONAIRE

The questionnaire begins on the following page and has been taken directly from the survey monkey website.

/ Surveys	Address Book	My Account	Plans & I	Pricing				+ Create S
	You hav	ve a BASIC accoun	t To remo	ve the limits of a l	BASIC account and ge	et unlimited question	s, upgrade now!	
(A Simul	lation Usabilit	y Study _{Edit}						
Edit Su	irvey				Preview Survey	Send Survey »		
To change the	he look of your survey, s	select a theme below	<i>w</i> .					
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				+ Add Page]			
AGE	Edit Page Options V	Add Page Logic	Move Copy	Delete			Sho	w this page only
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Overall Reactions to the System. Please select the numbers which most ap	propriate	ely reflec	t your impre	essions	s of using	this com	puter sys	tem. Not	Applicab	le = NA.
Terrible (1) to Wonderful (9)	1	2	3	4	5	6	7	8	9	N/A
Dull (1) to Stimulating (9)										
Difficult (1) to Easy (9)										
Rigid (1) to Flexible (9)										
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4 Edit Question V Move Copy Delete									
Select the number which most appropriately	reflect vour	impressi	ons of using t	he soft	ware or s	system, N	ot Applica	able = NA	L
	1 2	3	4	5	6	7	8	0	- Ν/Δ
Learning to operate the system. Difficult (1) to Easy (9)	· 2	0	-	5	U	i I	0	5	IWA
Getting started. Difficult (1) to Easy (9)									
Learning advanced features. Difficult (1) to Easy (9) Time to learn to use the system, Slow (1) to Fast (9) Exploration of features by trial and error.									
Discouraging (1) to Encouraging (9)									
Exploration of features. Risky (1) to Safe									
Discovering new features. Difficult (1) to Easy (9)									
Remembering names and use of									
commands. Difficult (1) to Easy (9)									
Steps to complete a task follow a logical									
sequence. Never (1) to Always (9) Feedback on the completion of the steps									
Unclear (1) to Clear (9) Remembering specific rules about									
entering commands. Difficult (1) to Easy (9)									
	+ Add Qu	estion V	Split Page He	ere					
5 Edit Question ▼ Move Copy Delete System Capabilities. Select the number which most appropriately	v reflect your	impressi	ons of using t	he soft	ware or s	system. N	ot Applic	able = NA	L.
	1 2	3	4	5	6	7	8	9	N/A
System speed. Too slow (1) to Fast enough (9)									
Response time for most operations. Too									
slow (1) to Fast enough (9)									
Rate information is displayed. Too slow (1) to East enough (9)									
The system is reliable. Never (1) to									
Always (9)									
Operations are. Undependable (1) to									
Dependable (9)									
System failures occur. Frequently (1) to									
Selaom (9)									

of	ility to undo opera Adequate (9) ase of operation d experience. Neve	ations. Ina epends o r (1) to A	adequate (1) n your level lways (9)	1 2	3 4	5 6	7 8	9 N/A
				+ Ad	d Question			
				+	Add Page			
AGE 3	Edit Page Opti	ions ▼	Add Page Logic	Move Copy Del	ete			Show this page
s. Ques nstruct	stonnaire Reg tions: This que ement serious o	stionna	the Use of	of statements a of poportunity to	bout your persor	nal attitudes at Each item rer	pout the use of the	e knee ent about vour
attitude or wron oersona oe truth anonyn	e toward your s ng answers. Yo al feelings abo nful and descri nous with the r	satisfact ou will p out each ibe your results b	ion with learn robably agree statement be attitude as it being compile	ing and self-cor e with some of the elow by marking really is, not whe ed as a group, not	fidence in obtain the statements an the numbers that the numbers that you would like ot individually.	ing the instruct d disagree wit at best describ e for it to be. T	ction you need. Th h others. Please i es your attitude o his survey is comp	nere are no right ndicate your ow r beliefs. Please pletely
				+ Ad	d Question			
Q 6	Edit Question V	Move	Copy Delete					
* Sat	tisfaction with C	ds used	earning STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY AGREE	N/A
in t and	this simulation are d effective.	e helpful						
wit ma prc	th a variety of lean aterials and activit pmote my learning	rning ies to g.						
The in t mc	e teaching materi this simulations ar otivating and help arn.	als used re me to						
lea								
lea				+ Ad	d Question			

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PAGE 4	Edit Page Options V Add Page Logic	Move Copy Delete			Show this page only
4.		+ Add Question ▼			
Q7 E * Self I an mas teau this It is	idit Question ▼ Move Copy Delete Confidence in Learning STRONGLY DISAGREE In confident that I am stering the content my chers present to me in simulation. my responsibility as the	DISAGREE UNDECIDED	AGREE	STRONGLY AGREE	N/A
stuc to k sim It is resy I ne sim	In to learn what I need now in these ulations. the teacher's ponsibility to tell me what red to learn in the ulation(s).	+ Add Question ▼			
		+ Add Page			
PAGE 5 5.	Edit Page Options V Add Page Logic	Move Copy Delete			Show this page only
		+ Add Question			
Q8 E * Obje	idit Question ▼ Move Copy Delete ectives and Information STRONGLY DISAGREE	DISAGREE UNDECIDED	AGREE	STRONGLY AGREE	N/A

There is enough information	STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY AGREE	N/A
provided at the beginning of the simulation to provide direction and						
encouragement. Independent problem- solving was facilitated. I clearly understood the purpose and objectives of						
the simulation.						
		+ Add	Question V			
		+.	Add Page			
PAGE 6 Edit Page Options ▼	Add Page Logic M	ove Copy Dele	te			Show this page only
	Convil Delete	+ Add	Question V			
* Fidelity and Realism	Copy Delete					
The simulation suspended disbelief. The scenario resembled a real-life situation. Real life factors, situations, and variables were built into the simulation scenario.	STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY AGREE	N/A
·		+ Add	Question V			
		+	Add Page			
PAGE 7 Edit Page Options ▼	Add Page Logic M	ove Copy Dele	te			Show this page only

7.							
			+ Add	Question V			
Q10	Edit Question V Move	Copy Delete					
* Co	omplexity and Cues						
		STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY DISAGREE	N/A
Th en cle pri Th pri sir	ne simulation provided nough information in a ear matter for me to oblem-solve the situation. here is enough information ovided to me during the mulation						
Th an un Er pr pr sir	notation. he cues are appropriate hd geared to promote my hderstanding. hough cues need to be rovided tome so I can rogress with the mulation.						
Th to an	ne simulation allowed me analyze my own behavior nd actions.						
			+ Add	Question V			
			+ /	Add Page			
AGE 8 8.	Edit Page Options V	Add Page Logic Mo	ove Copy Dele	te			Show this page on
			+ Add	Question V			
Q11 * Fe	Edit Question V Move	Copy Delete				0750.00.0	
Th op	nere are enough oportunities in the	STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY AGREE	N/A

variety ways of assessing

Using simulation activities make my learning time more

my learning.

productive.

simu	ulation to find out if I	STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY AGREE	N/A
clea mat I rec simu mar	rly understand the erial. ceived cues during the ulation in a timely mer.						
The simu clea unde	objectives for the ulation experience were r and easy to erstand.						
			+ Add	Question V			
			+ /	Add Page			
PAGE 9	Edit Page Options V	Add Page Logic M	ove Copy Dele	te			Show this page only
9.							
			+ Add	Question V			
Q12	Edit Question V Move	Copy Delete					
* Dive	rse Ways of Learning	STRONGLY DISAGREE	DISAGREE	UNDECIDED	AGREE	STRONGLY AGREE	N/A
The varie lear This	simulation offered a ety of ways in which to n the material.						

+ Add Question ▼

+ Add Page

AGE 10	Edit Page Options ▼	Add Page Logic	Move	Сору	Delete]	Show this page onl
10. Ser	ious Game Usabilit	y					
				+	- Add Que	estion V	
012		Question Logia M			alata		
QIJ We	re you able to navigate	easily throughou	ove Co	ppy D			
	Yes	cashy throughou			g room.		
	No						
Ad	ditional Comments?						
]
			+ A	Add Que	stion V	Split Page Here	
Q14	Edit Question V Add	Question Logic M	ove Co	opy D	elete		
Did	you have any difficulty	in interacting wi	th any c	of the a	avatars (characters), and/or resources (too	ls, etc.)?
	Yes						
	No						
Ad	ditional Comments?						
			+ A	Add Que	stion ▼	Split Page Here	
Q15	Edit Question V Add	Question Logic M	ove Co	opy D	elete		
We	re you able to access th	ne information yo	ou requi	red?			
	Yes						
	No						
Ad	ditional Comments						

+ Add Question ▼ Split Page Here	
Q10 Edit Question ▼ Move Copy Delete	
* What did you like best about using the serious game?	
+ Add Question ▼ Split Page Here	
Q17 Edit Question ▼ Move Copy Delete	
* What did you like least about using the serious game?	
+ Add Question	
+ Add Page	
AGE 11 Edit Page Options V Add Page Logic Move Copy Delete Show this	page or
11. Clarity of Content	
+ Add Question	
Q18 Edit Question V Move Copy Delete	
* What are some of the things you like about the way the content is presented? Is it easy to read the information? Is the layout	

		appealing								
]	
					+ Add Question	▼	Split Page Here	9		
219	Edit Question	▼ Move	Сору	Delete						
* Wh	nat are some of	the thing	s you do	n't like a	about the way the	conte	ent is presente	ed?		
L]	
					+ Add Question	▼	Split Page Here	•		
Q20	Edit Question	▼ Move	Сору	Delete						
★ls t	here anything	you would	change	regardi	ng the way the co	ntenti	is presented?			
					+ Add Question		Split Page Here	3		
					+ Add Question	V	Split Page Here	•		
221	Edit Question	▼ Move	Сору	Delete	+ Add Question	•	Split Page Here	3		
221 * ls t	Edit Question	▼ Move	Copy	Delete	+ Add Question	▼ e to se	Split Page Here	3		
221 * Is t	Edit Question	▼ Move	Copy ent/instr	Delete uctions	+ Add Question	■ ▼	Split Page Here	3		
Q21 * ls t	Edit Question	▼ Move	Copy ent/instr	Delete uctions	+ Add Question	■ ▼ e to se	Split Page Here))		
221 * ls t	Edit Question	▼ Move	Copy ent/instr	Delete	+ Add Question	e to s	Split Page Here)		
221 * Is t	Edit Question	▼ Move	Copy	Delete	+ Add Question	e to se	Split Page Here	3		
Q21 * ls t	Edit Question	▼ Move	Copy ent/instr	Delete	+ Add Question	e to se	Split Page Here	3		
)21 * ls t	Edit Question	▼ Move	Copy ent/instr	Delete	+ Add Question	e to so	Split Page Here)) 		
221 * Is t	Edit Question	▼ Move	Copy ent/instr	Delete	+ Add Question that you would like + Add Question	e to s	Split Page Here ee included? Split Page Here	3		

s there any other informatio	on/content that could be included in the serious game that you thin	
	+ Add Question	
	+ Add Page	
E 12 Edit Page Options ▼	Add Page Logic Move Copy Delete	Show this page
Dereention of Applicatio	an to Looming	
Perception of Application	on to Learning	
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22 500 5 2 400	+ Add Question ▼	
23 Edit Question ▼ Add Q	+ Add Question ▼ uestion Logic Move Copy Delete	
23 Edit Question ▼ Add Q Have you ever used serious	+ Add Question ▼ uestion Logic Move Copy Delete games in any of your courses in the past?	
23 Edit Question ▼ Add Q Have you ever used serious Yes	+ Add Question ▼ uestion Logic Move Copy Delete games in any of your courses in the past?	
23 Edit Question ▼ Add Q Have you ever used serious Yes No	+ Add Question ▼ uestion Logic Move Copy Delete games in any of your courses in the past?	
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Q24 * Do	Edit Question V Move Copy Delete
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Q25 Ple	Edit Question V Move Copy Delete
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	+ Add Page
GE 1	3 Edit Page Options ▼ Add Page Logic Move Copy Delete Show this page o
3. Pe	rceived Integration into Curriculum/Training Sessions
	+ Add Question ▼
Q26 * Do en	Edit Question V Add Question Logic Move Copy Delete o you think that serious games (e.g., simulations such as this) are useful in teaching and learning in today's learning vironment?
	Yes
	No
PI	lease explain.

+ Add Queston Split Page Here T L Add Queston Split Page Here T L Add Queston Split Page Here Add Queston Split Page Here + Add Queston Split Page Here + Add Queston Split Page Here + Add Queston Split Page Here Base explain. + Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Split Page Here Add Queston Spl					
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Add Question V Split Page Here 27 Edit Question V Add Question Logic Move Copy Delete Yes No Please explain. 28 Edit Question V Move Copy Delete 29 Edit Question V Move Copy Delete Where 29 Edit Question V Move Copy Delete What do you think are the major benefits to using serious games in teaching and learning?					
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Add Question Split Page Here 27 Edit Question Add Question Logic Move Copy Delete * Do you feel that serious games can enhance learning for students/trainees? Yes No Please explain + Add Question + Add Question Split Page Here 28 Edit Question Move Copy Delete * How would you integrate such a serious game into a curriculum (i.e., within a classroom, online, etc)? + Add Question * Add Question Split Page Here 29 Edit Question Move Copy Delete * What do you think are the major benefits to using serious games in teaching and learning? 					
27 Edit Question ▼ Add Question Logic Move Copy Delete ★ Do you feel that serious games can enhance learning for students/trainees? Yes No Please explain. + Add Question ▼ Split Page Here 28 Edit Question ▼ Move Copy Delete * How would you integrate such a serious game into a curriculum (i.e., within a classroom, online, etc)? + Add Question ▼ Split Page Here 29 Edit Question ▼ Move Copy Delete * What do you think are the major benefits to using serious games in teaching and learning?		+	Add Question V Split Page Here		
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Yes No Please explain. + Add Question ▼ Split Page Here 28 Edit Question ▼ Move Copy Delete * How would you integrate such a serious game into a curriculum (i.e., within a classroom, online, etc)? + Add Question ▼ Split Page Here 29 Edit Question ▼ Move Copy Delete * What do you think are the major benefits to using serious games in teaching and learning?	* Do	you feel that serious games can enhance lear	ning for students/trainees?		
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