Developing Game-based Leadership Training for Robotic Surgeons

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ABSTRACT

All surgeons must simultaneously perform as skilled practitioners and effective team leaders in the operating room. This is further complicated in robotic surgery because the surgeon is removed a short distance from the operating table and works from within a specialized cockpit. This separation creates a unique hurdle when a crisis arises that requires the surgeon to disengage from the immediate steps of the surgery to provide leadership and guidance with issues involving the team, the equipment, the room, or the patient.

To develop and test these skills we initially created a series of scenario-based videos with quizzes to evaluate surgeon understanding of these leadership responsibilities. Using these as a guide, we developed a game-based virtual environment containing the same information as the videos but in a 3D interactive space which is accessible through a web browser. This environment presents accessible and engaging scenarios that include a scoring mechanism which can assess the time to react to events, the actions that occur before and after a decision, and the correctness of the decision made. The tool can also present alternative or repetitive scenarios when the student does not take the correct action. This paper describes the development process and the interactions with the surgeons and operating room teams which drove the design and content of the virtual environment. The paper also describes the longer term plans to validate the content and introduction of the game to multiple surgical training sites around the country. Though the virtual environment uses a more interactive method for presenting leadership and team decision making information, we are interested in whether it is more effective than traditional didactic lectures, textual instructions, videos, and live role playing.

ABOUT THE AUTHORS

Roger Smith is an expert in the development of simulation devices and training programs. He has spent 25 years creating leading-edge simulators for the Department of Defense and Intelligence agencies, as well as accredited methods for training with these devices. He is currently the Chief Technology Officer for the Florida Hospital Nicholson Center where he is responsible for establishing the technology strategy and leading research experiments. He has served as the CTO for the U.S. Army PEO for Simulation, Training and Instrumentation (PEO-STRI); VP and CTO for training systems at Titan Corp; and Vice President of Technology at BTG Inc. He holds a Ph.D. in Computer Science, a Doctorate in Management, and an M.S. in Statistics. He has published 3 professional textbooks on simulation, 10 book chapters, and over 100 journal and conference papers. His most recent book is *A CTO Thinks About Innovation*. He has served on the editorial boards of the *Transactions on Modeling and Computer Simulation* and the *Research Technology Management* journals.

Alyssa D.S. Tanaka is a Systems Engineer at Florida Hospital Nicholson Center. Her research work focuses on robotic surgery simulation and effective surgeon training. Her current projects include rapid prototyping of surgical education devices, the validation of a robotic surgical curriculum and evaluation of robotic simulation systems. She is a Modeling and Simulation PhD student at the University of Central Florida and previously earned a M.S. in Modeling and Simulation, Graduate Simulation Certificate in Instructional Design, and a B.S. in Psychology and Cognitive Sciences from the University of Central Florida. She holds a diploma in robotic surgery from the Department of Surgery, University of Nancy, France.

Steve McIlwain is a Senior Producer for the Virtual Heroes Division of Applied Research Associates, Inc. He has over 10 years of production experience in the 3D animation and interactive entertainment industries. Prior to joining Virtual Heroes, Steve worked at Walt Disney Feature Animation and Blizzard Entertainment. He specializes in production management, macro/micro scheduling, team building, and finance. He is passionate about creating virtual worlds that educate, inform, and inspire. Steve holds a B.S. in Marketing and an M.B.A. from Azusa Pacific University

Bradley Willson is the Game Design Lead for the Virtual Heroes Division of Applied Research Associates, Inc. A nine-year veteran of the game industry, Brad began his career at Rockstar San Diego as a Development Support Supervisor, where he worked on various commercial game titles including the Midnight Club series, Table Tennis, and Red Dead Revolver. He joined Virtual Heroes in 2006, with the goal of incorporating his commercial game experience into games that had a true altruistic focus. At Virtual Heroes, Brad works to create, drive, and deliver the overall creative vision for the numerous serious games in development. Brad creates compelling software designs from conflicting viewpoints, communicates the designs to the development team, and translates the designs into detailed software mechanics, gameplay progression, and interface flow. Brad holds a B.S. in Wildlife Science from Purdue University.

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INTRODUCTION

Surgery is a team sport requiring the coordinated activities of multiple healthcare professionals. This team assembles daily in different combinations for a few hours with the chief surgeon as the leader who is responsible for directing the surgical activity. Historically, the surgeon has been the most highly educated member of the team, the most socially respected, and the most dominant personality. This has created situations in which the surgeon manages the team as a dictator who does not listen to the experience-based concerns and educated input from the other members of the team. Organizations like the American College of Surgeons and the World Health Organization have responded to these issues by creating and propagating standard practices and training materials which promote cooperative participation by all members of the team and an open, inclusive attitude by the surgeon/leader of the team. The surgeon remains the primary person responsible for the outcome of the surgery, but is encouraged or required to solicit and apply the expertise of all members of the OR team.

Robotic surgery with the da Vinci surgical robot, the dominant device in the field, introduces additional challenges for keeping a team working together. Changes in the physical location and orientation of team members create one new hurdle in team cooperation. Figure 1a illustrates the positions of typical members of a surgical team for open and laparoscopic procedures. Everyone is physically clustered around the patient, within arm's reach and easy speaking distance of one another. Direct eye-to-eye contact and communication is easy and directives to the team are difficult to confuse. By contrast, Figure 1b illustrates the positions of members of a robotic team. Most members remain at the bedside, but the surgeon has been separated from the encircled group. In order to operate the robot, the surgeon must remove himself from the bedside and take a position within a custom console to control the machine. This console pulls their physical actions, visual attention, and mental focus into an environment that is separate and unique from the rest of the team. This situation can potentially undermine the previous work that has been done to integrate the actions and expertise of the team within more traditional forms of surgery.

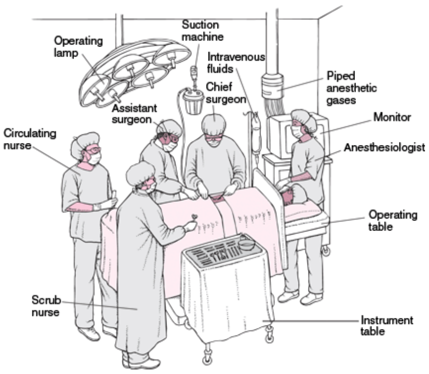


Figure 1. Traditional vs. Robotic OR Team Positions.

The manufacturer of the da Vinci robot has attempted to mitigate this separation by including a microphone and speakers in the head-space of the robotic console. So the words spoken by the surgeon are broadcast to the rest of the team from speakers attached to the bedside components of the robot. Similarly, a microphone on the bedside equipment captures the discussions of the surgical team and carries it to speakers in the surgeon's console immediately next to the surgeon's ears. External monitors around the bedside also display the picture of the internal surgery which the surgeon is seeing within the console. So all members share a common view of the inside of the patient and can talk to each other as if they remained around the bedside within arm's reach of each other.

To teach and reinforce team management and leadership for surgeons there have previously been video instructions and role playing scripts that walk through each of the skills which have been identified as essential for surgical teams. The video recordings present previously enacted situations which can contain both correct and incorrect activities that the surgeon/student can be evaluated on through questionnaires following the video. But the situations do not require interactive participation by the surgeon. Live role playing events allow the surgeon and all of the actors to experience multiple variations on the situation and to explore unique ideas which emerge in real time. However, these are extremely difficult to coordinate and host. The working schedules of surgeons, circulating nurses, surgical technicians, and anesthesiologists are very different. Each profession is guided by different certifying boards, departmental management, educational requirements, and working hours. Arranging for live events within a hospital or at a professional conference can be nearly impossible with real professionals. At some educational conferences, these events have been organized using hired actors for the members of the team. These remain expensive and rare events. Though these methods have proven useful, some of their limitations may be overcome through a computerized, interactive, game-based learning environment.

This paper describes a project to create a surgeon leadership and team management virtual environment which could be used at a robotic surgeon's leisure. This environment can include more variations in activities than can be easily captured in videos and can provide some of the richness of live role-playing events, but without the expense and logistical hurdles.

This paper describes the process used to design, prototype, and field the virtual world application. The application is currently in final in-house testing and will be released for open community testing in the near future. After that it will become the basis for a validation trial focused on its educational effectiveness.

BACKGROUND

The robotic surgery team training virtual world (RoboTeamView) is the sixth product of a larger effort to create materials for the Fundamentals of Robotic Surgery (FRS) program, an authoritative, standardized curriculum for certifying the knowledge and skills of aspiring robotic surgeons (Smith, Patel, Satava, 2013).

The FRS program has leveraged the expertise of more than 50 of the leading robotic surgeons in the world as well as a number of educational and engineering professionals, to develop materials which surgical educators can use to bring new surgeons to a common, measurable, and professionally accepted level of proficiency prior to performing surgery on human patients (see Figure 2). These materials include:

a. Online Curriculum consisting of text, slides, photos, and videos for teaching the cognitive knowledge needed by robotic surgeons;
b. Psychomotor Skills Device which measures the tactile skills of a surgeon using the robot;
c. Team Training videos which convey material similar to that included in the RoboTeamView game;
d. Team Training Role Playing Script which can be acted by live role-players;
e. Intuitive Surgical da Vinci Skills Simulator (DVSS) exercises;
f. Mimic dV-Trainer simulator exercises;
g. Simbionix Robotix Mentor simulator exercises; and
h. Robotic Surgeon Team Training Virtual World (RoboTeamView) for teaching team skills to a surgeon who is training alone.

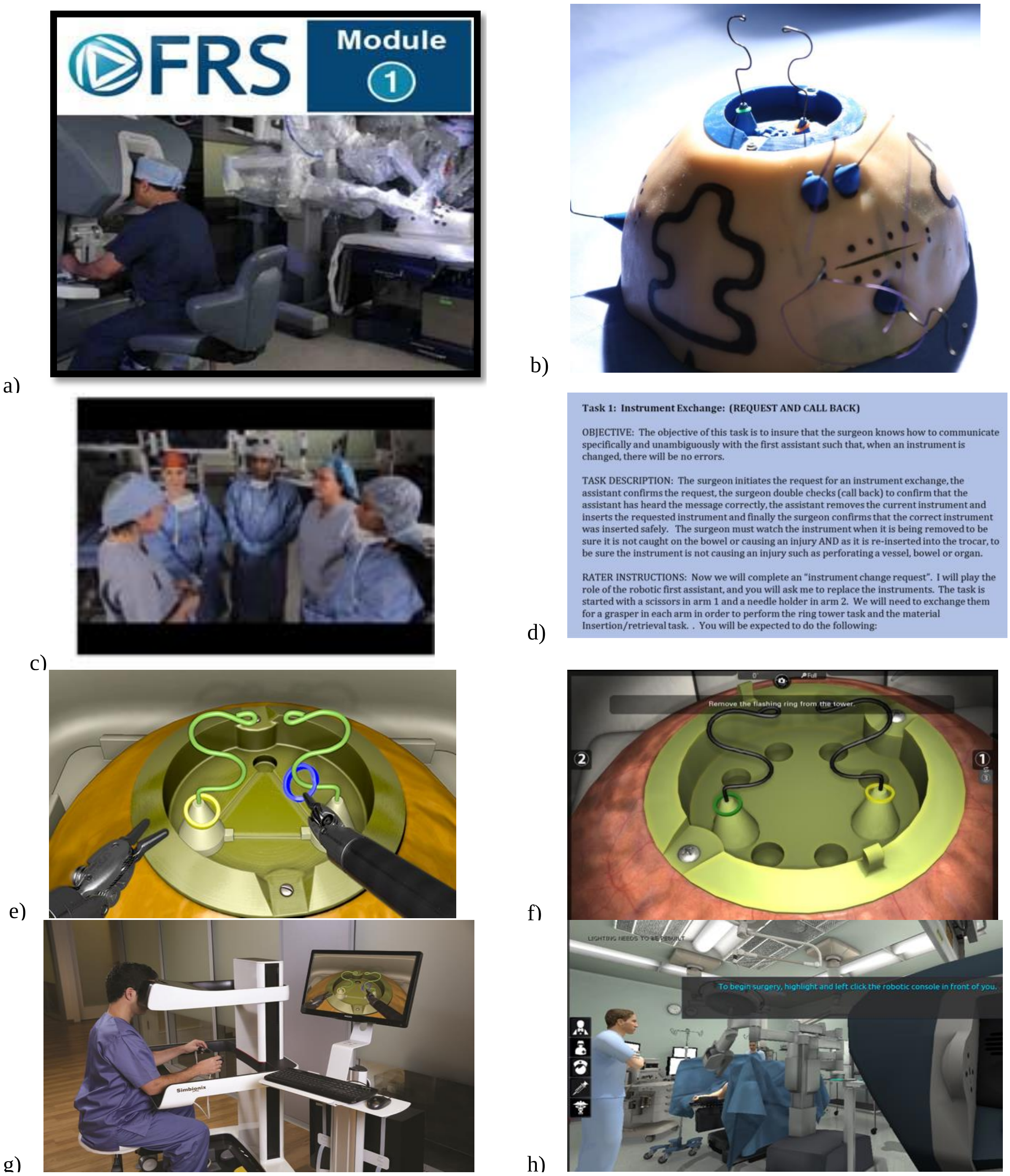


Figure 2. Fundamentals of Robotic Surgery Curriculum Products – (a) online curriculum, (b) psychomotor skills device, (c) team training videos, (d) role playing script, (e) Intuitive DVSS simulator, (f) Mimic dV-Trainer simulator, (g) Simbionix Robotix Mentor simulator, (h) RoboTeamView virtual world.

METHODOLOGY

This project used the ADDIE process for design and development of the learning application (Branch, 2010).

Analysis of Problem.

Surgeons with years of experience in bedside surgery (open and laparoscopic) described a sense of separation from the operating team when they began using the robot for procedures. In spite of the video and audio assistive tools which allow members of the team to communicate with each other, the physical separation and lack of direct line-of-sight to the team allowed the surgeon to immerse himself in a private world during a procedure. Effective communication with the team became something that required a higher level of conscious effort to maintain throughout a procedure. Surgeons needed to learn when to use the communication tools in the robot and when to disengage from the robot in order to handle situations which required more direct human-to-human contact (Hanly et al, 2006).

Analysis of Users.

There are two primary users of this virtual world. The first are attending surgeons, fellows, and residents who aspire to practice robotic surgery. The second are experienced robotic surgeons who require additional training in working effectively with a team. Both groups have limited time to focus on new curricula beyond their current work load. Both must learn independently in an environment that they access themselves. They do not have dedicated classrooms, equipment, instructors, and class hours as do traditional university students. In most cases, the student is expected to learn on their own time and without the collaboration of other members of the OR team.

Analysis of Environment.

The users typically possess extensive medical and surgical skills, but very limited computer skills. They are typically not proficient at installing new applications on computers, or they are using machines that are controlled by corporate IT restrictions which prohibit unauthorized applications. These characteristics led to a focus on a web-based application with a plug-in which auto installs if needed, and which can be approved for use across the corporate environment.

Design of Instruction.

Instruction is based on the widely used TeamSTEPPS curriculum (Safny et al, 2011; Thomas and Galla, 2013) and WHO checklists for surgery (WHO, June 2008). This material is then modified for application in a robotic OR environment. The exchanges with team members in this environment are largely prescribed and standardized to reduce miscommunication and the omission of important steps. The instructions for the game were based on prior work to create role-playing scripts for robotic OR team members.

Design of User Experience.

The primary instructional environment is a virtual robotic operating room which is populated with four avatars representing the other members of the team. The surgeon is either viewing a surgical field inside of a patient or the team around the operating table. In the former case, the surgeon interacts with a surgical video using menu selections at key decision points. In the latter, the surgeon queries an avatar for information and gives it instructions to be followed. The primary goal of the environment is to lead the surgeon through specific scenarios and assist them in understanding the correct actions that they should apply. This is primarily a learning environment and secondarily an assessment tool.

Development of Virtual Environment.

Virtual Heroes has previously created a number of healthcare virtual worlds which included digital assets that appear in this virtual world. The essential new asset which had to be created was a 3D model of the da Vinci surgical robot, a complex piece of machinery with many visible pieces. The robotic arms and hand controls need minimal animations for these team scenarios. More work was required for the multiple menu items necessary to present all of the decision actions of the team.

Development of Video Integration.

The project required the integration of 3D virtual world assets with prerecorded videos of the surgical field. These videos were drawn from the extensive video library of a leading robotic urologist and some videos were custom made during live surgeries. From these we were able to select segments of surgeries which corresponded to the lessons being taught in the virtual world. Synchronizing virtual actions with video events allowed us to avoid creating virtual representations of complex internal human anatomy and the manipulations of those models.

Development of Evaluation Criteria.

The scenarios provide multiple decision points at which a surgeon/student must select the correct response from a small list of options. The correct selection will lead to acceptance by the avatars and progression to the next step. An incorrect selection will cause the avatars to offer advice or to ask leading questions to guide the surgeon to a correct action. Performance evaluation is a summation of the correct and incorrect actions taken by the surgeon during each scenario. Benchmarking those scores will be part of a future validation process in which proficiency levels will be established based on the scores of expert and novice subjects.

Implementation of Training Program.

The training program will be implemented in multiple steps. Initially, the RoboTeamView will be made available to a small number of robotic surgeons who assisted with the development of the new curriculum. They will provide feedback during the early releases to assist in reprogramming or redesigning features of the application. The secondary release will be to a community of expert robotic surgeons who have contributed to the creation of previous FRS program materials. These experts are the conduits for sharing the application with aspiring robotic surgeons at multiple hospital systems and organizing a validation trial using surgeons, fellows, and residents. Finally, the application will be made publically available at no charge for access by anyone who is interested in using it for their own personal learning or as a tool within in an educational environment.

Evaluation of Effectiveness.

Acceptance of this material by instructors and institutions for education in robotic surgeon training is an encouraging and valuable achievement. But it does not constitute scientific evidence of validity as an effective teaching tool. This will be achieved via a multi-site validation trial of the tool with the goal of demonstrating that it is an equal or better method of teaching team leadership skills than the existing methods.

DEVELOPMENT

Data Acquisition

The development process began with the acquisition of knowledge and data. The game development team observed multiple procedures in the robotic operating room. They were able to watch and listen to all of the activities that occurred, and to see each member's role throughout a procedure. They also witnessed the transition of nursing support staff completing a shift or leaving for a break during a procedure. Following this exposure, robotic surgeons were interviewed, introduced to the product concept, and provided their guidance on how such a product could be structured for effective education. An analysis of the published literature of the use and availability of simulators or virtual worlds for robotic surgeons indicated that a leadership-focused tool for team communication skills had not previously been created (Kumar, Smith & Patel, 2015). Therefore, many of the educational design concepts of this project were being created for the first time.

The team reviewed existing curriculum in textual script and video recording formats. These were based on best practices which have been created by the TeamSTEPPS program and the World Health Organization for safe communications in the operating room. Together with the data collected from the surgeons, the team arrived at a small set of scenarios to be included in the virtual world, as listed in Table 1.

Table 1. Surgical Scenarios Created

S1.	Instrument Exchange (Request and Call Back)
S2.	Material Insertion & Retrieval (Request and Call Back)
S3.	Two-challenge Rule for a Safety Issue (CUS and SBAR)
S4.	Personnel Change (Handoff Responsibilities)
S5.	Check Back
S6.	Emergency Robotic Undocking Procedure
S7.	Pre-Brief (Checklist or Sign-in)
S8.	Post-procedure Debrief (Checklist or Sign-out)
S9.	Recoverable Robotic System Fault
S10.	Non-recoverable Robotic System Fault
S11.	Broken Instrument
S12.	Difficulty Removing/Reinserting an Instrument
S13.	Loss of Insufflation of Patient

The game calls for a combination of 3D computer graphic assets and live surgical videos. Through the cooperation of several surgeons the project received access to an extensive library of thousands of surgical videos. These videos are all usable for educational purposes through signed releases from the patients. As specific scenarios and 3D actions were developed, the team located an existing surgical video with actions which corresponded to the scenario. Using such a large video library made it possible to avoid either video recording a simulated surgery or attempting to create a realistic virtual representation of all of the surgical activities. In spite of the size of this library, it was necessary to custom record some actions during surgeries for this project. The current level of simulation technology is challenged to graphically model human tissue with manipulation, dissection, and blood flow. Some surgical VR simulators contain very realistic, but limited representations of surgery which require significant computer hardware to run. For this reason this project relies on video recording to represent actions in the surgical field, which comes with some inherent limitations to interactivity.

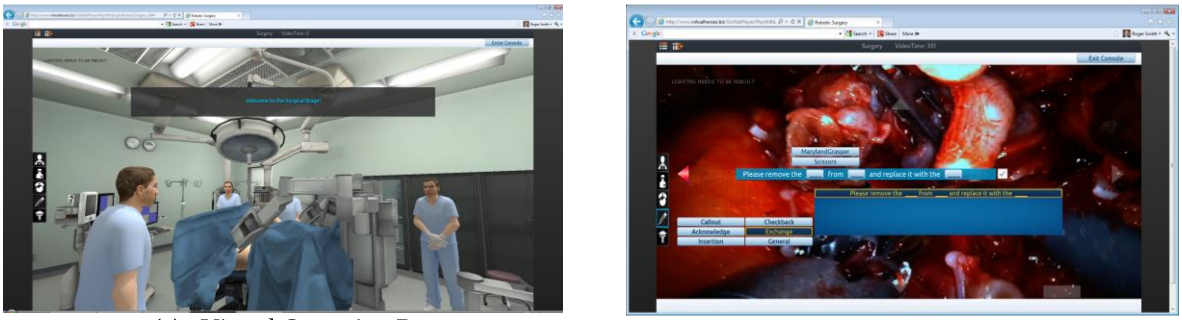
User Experience

Role Definition

Early discussions within the development team and with surgeons were focused on who would be the training audience for the tool. Since there are five members of the OR team who must learn to work together, should this tool provide a user interface and curriculum for each of these as potential trainees? Such a flexible tool seemed possible since the scenario is the same for each role, only requiring the removal of one script to allow a human user to play that part. However, since there were no previous tools of this type to use as guidance, solving such a multifaceted problem could lead to confusion and delays that would threaten the success of the project. Also, achieving acceptance of the tool from five different sets of professional and certifying organizations seemed to be a much larger problem. Therefore, the design focused only on training the surgeon, as was done with previous curriculum products. But, the virtual world and other training products may become the basis for variants that are targeted at the circulating nurse, first assistant, surgical technician, or anesthesiologist in the future. Since the game creates a single-user domain, there is no need for computer servers to coordinate the interactions of multiple players within the same scenario. A single scenario can be served to any number of users simultaneously, but each of these runs independently without the need for coordination between multiple players.

Dual Domains

During a procedure, the surgeon occupies two very different domains. One is as a member of the team that surrounds the operating table to address the patient from the outside. The other is a more private domain in which the surgeon is immersed within the internal anatomy of the patient with audio communication to the outside team (see Figure 3). In the scenarios which are to be represented (Table 1) it is most accurate for the surgeon to act within both of these domains, which requires creating a simulated environment of both. Previous training curriculum in video and script formats had presented the OR only from the external bedside view, while existing simulators provided only the internal view. This game is the first to include two very different domains in which the surgeon is learning. For some scenarios a surgeon remains immersed in the patient while responding to the team and giving direction. But for others, the surgeon needs to learn to disengage from the internal view in order to address a more important issue in the external OR. Learning which domain is most appropriate for the surgeon has become part of the training that is uniquely provided by this game.



(a) Virtual Operating Room (b) Video Surgical Field

Figure 3. Virtual World Representation

Session Independence & Progression

When a surgeon proceeds through a scenario, their progress is stored on the local computer. This allows users to interrupt their progress through a scenario, but return to the same point when they pick-up the game at a future time. Information about progression is also exported to the Moodle Learning Management System (LMS) to provide scoring and evaluation of the players. When a surgeon chooses to terminate a scenario prior to completing it, the LMS has a record of progress that has been made. In future versions this information will make it possible for the surgeon to complete a scenario from multiple devices by loading past progress from the LMS. This capability is a potential extension should early users discover that it is an essential feature.

Security

Like most corporate environments, the hospital IT infrastructure is tightly controlled and monitored to protect again hostile external and internal actions. It also blocks certain private and social services which are not considered productive in a corporate environment. As a result, many ports and some data formats cannot be used by applications like this virtual world.

The application was designed for Windows 7 and 8 operating systems and the Internet Explorer v.7+ browser because these are the most common within the hospital. Virtual Heroes bases many of their custom projects on the Unreal engine licensed from Epic Games for simulation projects. This engine and the game content are configured as a one-time browser plug-in to eliminate issues with asking users to perform multiple heavy downloads and installations. As a plug-in, this process is largely automated upon first use of the application. However, corporate IT restrictions still verify that the plug-in is permitted within the controlled hospital infrastructure. Therefore, the plug-in was treated as a new application which had to be reviewed for security and stability issues before being allowed to enter a hospital computer.

Additionally, once installed, the plug-in communicates with the LMS via unique ports and data formats which had to be approved to traverse the hospital network (see Figure 4).

The application was originally developed and shared from a Virtual Heroes server, and was then tested on personal computers on an open commercial network. Once a basically functional version existed, a hosting site on the internet was created which required a fresh install away from the Virtual Heroes machines. This demonstrated that the application was portable enough to be hosted on a customer's servers as opposed to the developer's servers. Finally, the hospital IT department created a hosting site within the hospital infrastructure, approved the plug-in on hospital computers, and opened the necessary communication ports for the application. The goal is to host the application on a site which can be accessed by surgeons both inside and outside of the hospital infrastructure. Robotic surgeons who are not employees of Florida Hospital will access the external site.

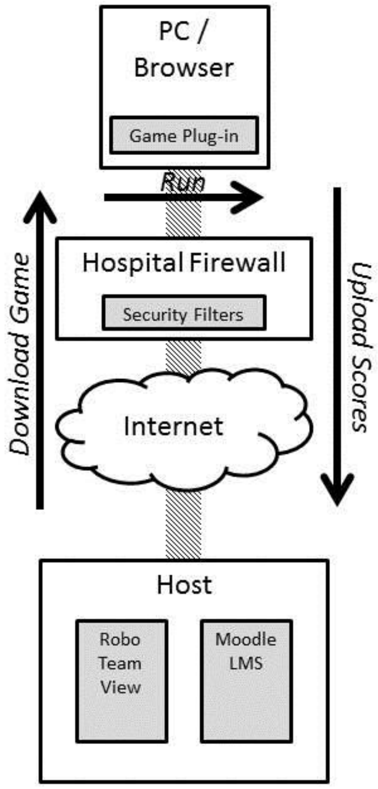


Figure 4. RoboTeamView System and Network Architecture

User Evaluation

The performance of the surgeon is evaluated as they interact with the scenarios and the dynamic avatars in the game. The application provides very direct guidance regarding the steps that are expected. The intention was for the game to be more of an educational environment than an assessment tool. The design allows surgeons to work through the scenarios without a human instructor and to learn the necessary information for performing as a team leader. There are numerous opportunities for a surgeon to make decisions, each of which is captured in the LMS to provide some measure of their performance. But, an attentive surgeon can learn the correct responses from the avatars without having to consult a human instructor. Therefore, the measurements of performance are actually a measure of the surgeon's ability to learn and adapt to the guidance of the avatars in the game.

Each surgeon logs into the system to create a record of on-going performance in the LMS. The Moodle LMS also provides login for an instructor who can access all student performance data. This allows a hospital, college, or education center to track the performance of their people and to insist on a specific level of mastery in association with credentialing, risk management, and educational progression.

VALIDATION AND DEPLOYMENT

The virtual world application has been completed and is being evaluated by experienced robotic surgeons and teaching faculty at Florida Hospital. The feedback from these professionals will be incorporated into the application before releasing it to a larger audience for independent and objective validation trials. The FRS project has developed research relationships with a number of leading medical institutes around the world. These have participated in the validation of previous FRS products and have shown their ability to organize and conduct these types of trials. The sites listed in Table 2, as well as others who have shown interest in the materials, will be invited to access this application and participate in a multi-site validation trial.

Following these trials, the revised application will be made available on the TrainRobotic.com web site for aspiring robotic surgeons, instructors, and medical training facilities to use as a curriculum for training robotic surgeons in their leadership responsibilities within the OR. Users of the application will be able to track student performance via the linked LMS.

Table 2. Robotic Surgery Curriculum Validation Site List

Florida Hospital Nicholson Center, Orlando FL	Lahey Health and Medical Center, Boston MA
University of Athens Medical School, Greece	Hartford Hospital, Boston MA
Imperial College, London UK	Louisiana State University School of Medicine, New Orleans
EndoCAS, Pisa Italy	Madigan Army Medical Center, Seattle WA
Baylor University Medical Center, Dallas TX	University of South Florida Health CAMLS, Tampa FL
Carolinas Healthcare System, Charlotte NC	Methodist Medical Center MITIE, Houston TX
Lehigh Valley Health Network, Allentown PA	University of Pennsylvania Medical Center, Philadelphia
Duke University Medical Center, Raleigh NC	

CONCLUSIONS

The primary goal of this project was to determine whether an effective leadership training application could be created for robotic surgeons who must learn to lead a team in the OR while performing surgery. The bulk of the efforts went into identifying which scenarios should be represented and how the information should be structured to create an effective training tool. The resulting product demonstrates that such an application can be created and that it satisfies potential users. As of this writing, the tool has not been used to train surgeons, fellows, or residents in OR team leadership. Neither has a validation trial been conducted to compare the effectiveness of this method against existing methods, e.g. didactic lectures, textual instructions, video recorded cases, and live role playing events. The next step is to conduct such a validation trial to determine whether the application is effective at teaching these skills to robotic surgeons. The results of these experiments and educational experiences are potential topics for future publications.

Questions that remain outstanding include:

- Will experts and instructors incorporate the application into their curriculum?
- Do surgeons who use the application actually have better patient outcomes?
- Is the application better than or equal to existing methods of teaching these skills?
- Is the product sustainable over a period of years, both financially and as educational content?

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