Award Number: W81XWH-11-2-0158

TITLE: Medical Robotic and Telesurgical Simulation and Education Research

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CONTRACTING ORGANIZATION: Adventist Health Systems Inc.
Orlando, FL 32803

REPORT DATE: September 2016

TYPE OF REPORT: ANNUAL

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
September 2016	Annual	01-Sept-2015 to 31-Aug-2016

4. TITLE AND SUBTITLE
Medical Robotic and Telesurgical Simulation and Education Research

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W81XWH-11-2-0158

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Roger D Smith, PhD

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Adventist Health Systems Inc.
Orlando, FL 32803

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)
USAMRMC TATRC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Best contact is via email. Office telephone is not reliable. roger.smith@flhosp.org

14. ABSTRACT
This project is broken into two focus areas: telesurgery and surgical rehearsal. In each we are exploring various applications and extensions of the existing robotic surgical systems. Under telesurgery we are exploring the ability to perform telesurgery using a robot both across a state-wide and a nation-wide area based on the currently available technology. Under surgical rehearsal we are exploring designs for simulator systems which can be used to improve training and education of surgeons pursuing expertise in the use of robotic surgical systems. The focus is on unique forms of robotics which have not previously been addressed by simulation technologies.

15. SUBJECT TERMS

Nothing listed

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					USAMRMC
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	UU	133	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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Introduction

This project is broken into two focus areas: telesurgery and surgical rehearsal. In each we are exploring various applications and extensions of the existing robotic surgical systems. Under telesurgery we are exploring the ability to perform telesurgery using a robot both across a state-wide and a nation-wide area based on the currently available technology. Under surgical rehearsal we are exploring designs for simulator systems which can be used to improve training and education of surgeons pursuing expertise in the use of robotic surgical systems. The focus is on unique forms of robotics which have not previously been addressed by simulation technologies.

The original term of this project was September 2014 to August 2016. However, on April 6, 2016, Florida Hospital requested a no-cost extension of 6 months to the term of the agreement, for a new end date of February 28, 2017. On May 13, 2016, the government granted this extension. Therefore, this annual report covers the period from September 2015 to August 2016, but does not align with the end of the project. A separate final report will be filed by March 30, 2017 to terminate the entire agreement.

Reporting Period: September 1, 2015 to August 31, 2016.

Statement of Work

Original Term of Project

Telesurgery: Metropolitan Latency. Perform robotic surgical experiments between multiple campuses within a metropolitan area, between campuses across a state area, and across nationwide campuses.

Period 1 Milestone: Telesurgery state-wide latency data and report. Award + 360 days.
Period 2 Milestone: Telesurgery nationwide latency data and report. Award + 700 days.

Surgical Rehearsal. Develop virtual reality environment for training operating room staff in robotic surgery. Develop design for simulators in hard-tissue robotic surgery (spinal and orthopedic).

Period 1 Milestone: Spinal simulator design document. Award + 300 days.
Period 2 Milestone: OR team training virtual world environment. Award + 360 days.
Period 2 Milestone: Orthopedic surgery rehearsal validation report. Award + 720 days.

Modifications from May 2015 Extension

Surgical Rehearsal. Develop design for simulators in hard-tissue robotic surgery (spinal and orthopedic).

Milestone 1: Spinal simulator design document. February 28, 2107.
Milestone 2: Orthopedic simulator design document. February 28, 2107.

Evaluating Simulator Metrics. Compare the metrics assigned by expert surgeons to those assigned by the simulator software.

Milestone 1: Simulator Metric Evaluation Document. February 28, 2107.

Project Management

Progress Summary.

- OR Team Training Virtual World has been completed and the application has been posted on the open internet for world-wide access. See www.TrainRobotic.com .
- Telesurgery experiments with all sites are complete.
- Robotic Spinal Surgery Simulator system and user analysis are complete. We are writing the final design document to be delivered in February 2017.
- Robotic Orthopedic Surgery Simulator system and user analysis are complete. We are writing the final design document to be delivered in February 2017.
- Evaluation of simulator metrics is processing subjects through the experiment.

Schedule.

This schedule shows our expected progress and completion of the experiments remaining on this grant.

Category	**Project**	**Y4Q4**	**Y5Q1**	**Y5Q2**	**Y5Q3**	**Y5Q4**	*****	**Y6Q1**	**Y6Q2**
Simulator Evaluations									
	Simulator Perform	■	■						
	Eval Sim Metrics				■	■	■	■	■
Robotic Simulator Design									
	OR Virtual World	■	■	■	■				
	Spinal Robotics			■	■	■	■	■	■
	Orthopedic Robotics			■	■	■	■	■	■
Telesurgery									
	Comms Latency	■	■						

'*' indicates current time at report

Budget.

Following the extension of the term of the project, financial spending on the project is aligned with the expected task and schedule completion for the project.

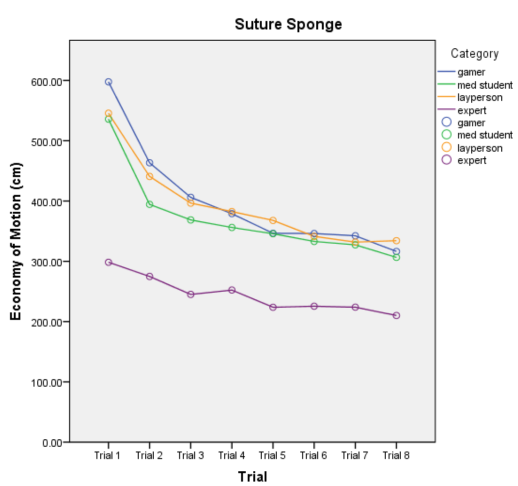
Scientific Progress

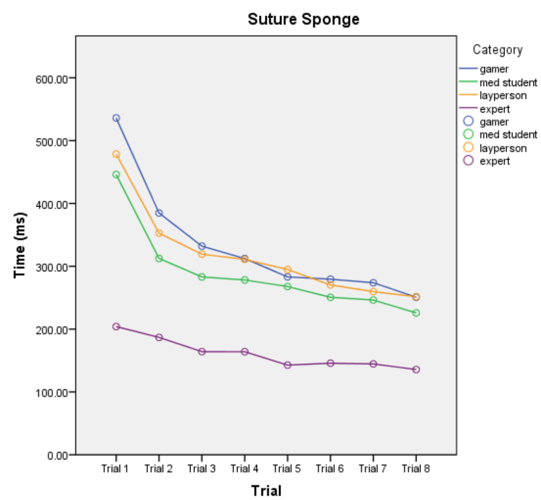
Simulator Performance.

Human subject data collection is finished. Expert surgeons were the most challenging population to collect. We collected data from Celebration Health, Columbia University Medical Center, and at the annual meeting of the Society for Laparoscopic Surgeons.

We are beginning full analysis of the data from all populations included in the study. The results of this work were presented at the 2015 I/ITSEC conference and the 2016 IEEE Serious Games in Healthcare Conference; served as the basis for one doctoral dissertation; and have been published in the *Journal of Surgical Endoscopy*.

A basic plot of the performance of four different populations while performing the Suture Sponge exercise is provide below (lower scores indicate higher skill levels in "economy of motion" and "time to complete"). This shows a very distinct performance difference between the expert surgeons and all other populations. It also appears that there is little difference between the population of lay people, medical students, and video gamers. The conclusion of the study is that subjects who are expert video game players **do not** exhibit skills in surgical simulation which are equivalent to practicing robotic surgeons. Rather, their performance is similar to all other subject categories who have little/no robotic surgery experience.





Evaluation of Simulator Metrics

We are processing subjects through this experiment. We currently have 23 subjects with a goal of 70 for completion. A preliminary analysis of the data from the current subjects has been performed and will be presented at the annual AAGL Congress in November 2016.

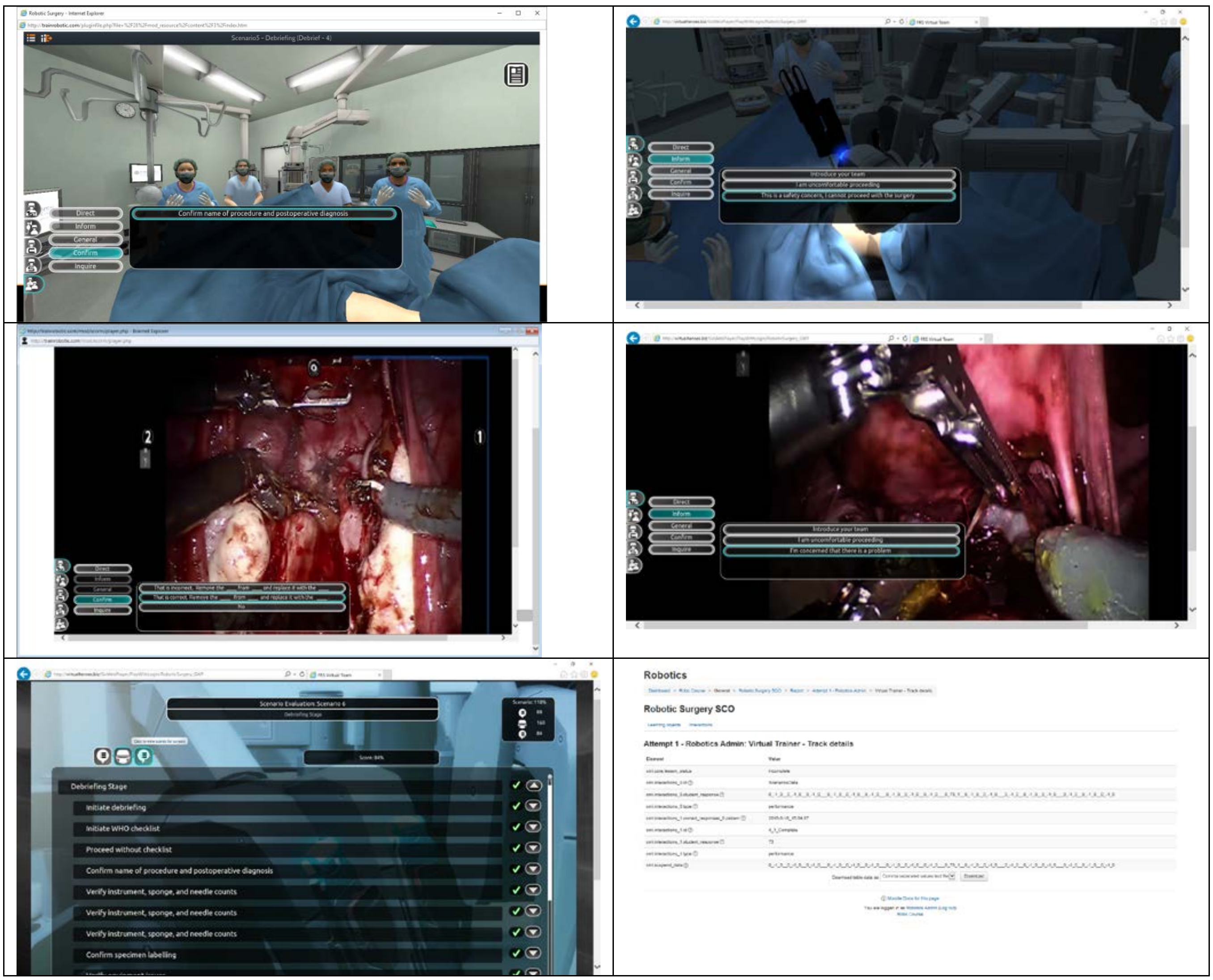
da Vinci OR Virtual World

This virtual world has been completed and made publicly available for access on the open internet. Interested parties may access and use the application at no cost. The hosting fees for the application will be paid by Florida Hospital to make it accessible to the public.

Users may choose to create a unique account so their personal scores can be tracked and reported to their institution. Or they may choose to use it through a "guest" account in which performance is not scored.

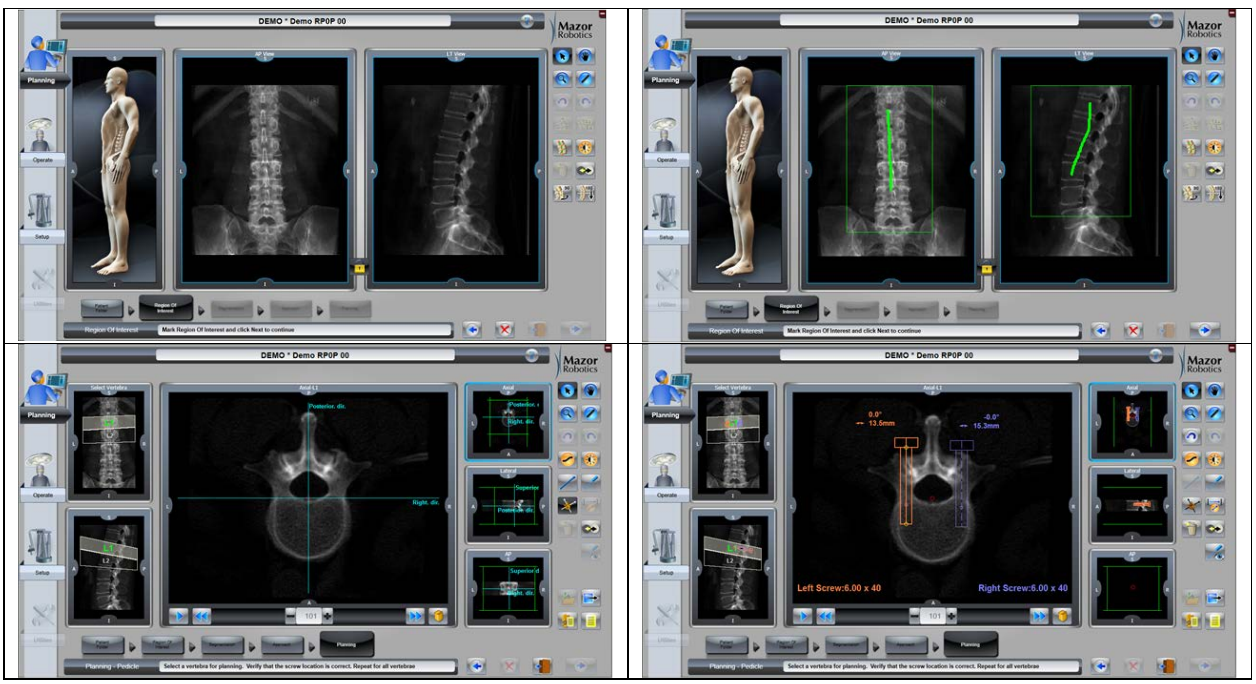
The application can be accessed at: www.TrainRobotic.com

A paper on this project was presented at the 2015 I/ITSEC conference. The finished game has been entered into the 2016 I/ITSEC Serious Games Showcase and Challenge.



Spinal Robotic Simulator

We have completed our analysis of the Mazor Spinal Robotic system as well as our analysis of the potential trainees. We are preparing the simulator design document for delivery in February 2017.



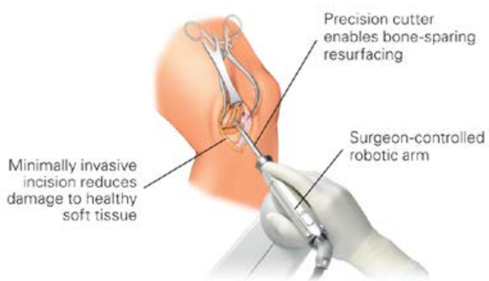
Mazor Simulator Assessment Strategy

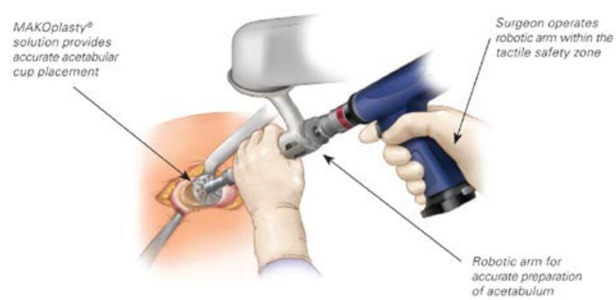
Skill	Objective	Domain	Item/Criteria	Media & Tool Selection
Properly upload/open patient's imaging	Demonstrate the procedure needed to import unique CT scans or open CT scan from exercise/patient data base.	Knowledge	Choose the option to upload patient specific CTs from their own collection or chooses a certain CT pertaining to pathology they wish to manipulate. Use planning tab and upload icon from the system. CT must follow Mazor's protocol (i.e., low-dose, 1mm contiguous axial slices). Choose to open pre-existing cases from the planning tab in the system.	Virtual
Select the Region of Interest (ROI)	Determine and select the correct vertebral bodies for given pathology.	Knowledge	Use the steps below to select ROI: 1. Draw a line on the correct vertebral bodies. 2. Include a body above and below ROI. 3. Mark path of vertebral foramen (in both AP and lateral view)	Virtual
Appropriately perform ROI segmentation.	Determine the vertebral units of the ROI.	Knowledge	Separate the vertebral column into vertebral units. Segmentation should not cut through end plates.	Virtual
Correctly label vertebrae	Accurately label vertebrae	Knowledge	Select and label one vertebra in the ROI to populate the remaining vertebra in ROI.	Virtual
Choose the proper hardware for preoperative plan	Accurately choose the proper hardware needed for case specific images.	Knowledge	Choose place screw option. Incorrect hardware (e.g., screws) will not appropriately fit the pathology when shown	Virtual
Correctly place hardware during preoperative planning	Determine and place the hardware in the preoperative stage.	Application	Use the steps below: 1. Place the screws. 2. Change implant parameters per case. 3. Use the software to play through 1mm slices of the image to accurately view placement. 4. Learner adjusts if screw placement looks incorrect.	Virtual
Identify correct platform	Determine the platform indicated by patient's pathology.	Knowledge	Chooses a platform that is appropriate to successfully complete the operative stage.	Physical Model
Properly place the registration 3D marker	Complete the required registration process to match preoperative CT with intraoperative fluoro image.	Application	Use the steps below to register the intraoperative image: 1. Calibrate C-Arm using the correct marker. 2. Properly attach the 3D marker.	Virtual/Physical Model
Accurately determine an appropriate fluoro image using RBC	Determine if intraoperative image is acceptable for image registration.	Analysis	Learner must examine image using the following: 1. The ROI is clearly shown in the image. 2. All of the beads from the 3D marker are captured. 3. Image shows clear vertebral anatomy	Virtual
Properly mount chosen platform	Demonstrate procedural	Application	Depending on the platform chosen, learners will: 1. Choose the correct corresponding tools and	Physical Model

	knowledge for mounting the correct platform.		hardware. 2. Determine which part of the bony anatomy to mount to. 3. Mount parallel to the spine. 4. Mount platform using the correct order of operations. 5. Tighten from a neutral position.	
Use guidance system	Using registered image and preoperative plan, execute the guidance system.	Application	1. The learner should ensure the preoperative plan is correct. 2. Gather tools needed (given by software, determined by preoperative plan). 3. Place robot using provided navigation. 4. Execute the robot using the software. 5. Wait for the robot to stop moving (or when the blinking stops).	Virtual/Physical Model
Place hardware (i.e., cannulas)	Determine correct hardware, demonstrate hardware placement.	Application	Depending on case/exercise: 1. Use simulated physical or virtual hardware to indicate placement of cannulas. 2. Interpret tactile feedback to adjust or maintain positioning.	Physical Model/Virtual
Properly use surgical tools (i.e., drill, k-wires, and screws.)	Demonstrate the procedural knowledge and skills to place the instruments for the procedure.	Application	1. Ensure drill doesn't skive. 1.1 If so, remove tissue using simulated hammer 2. Interpret tactile feedback to adjust or maintain positioning. 3. Remove drill. 4. Place k-wires. 5. Insert correct hardware. 6. Continue until all trajectories are reached.	Physical Model/Virtual

Orthopedic Robotic Simulator

We have completed our analysis of the Mako Orthopedic Robotic system as well as our analysis of the potential trainees. We are preparing the simulator design document for delivery in February 2017.

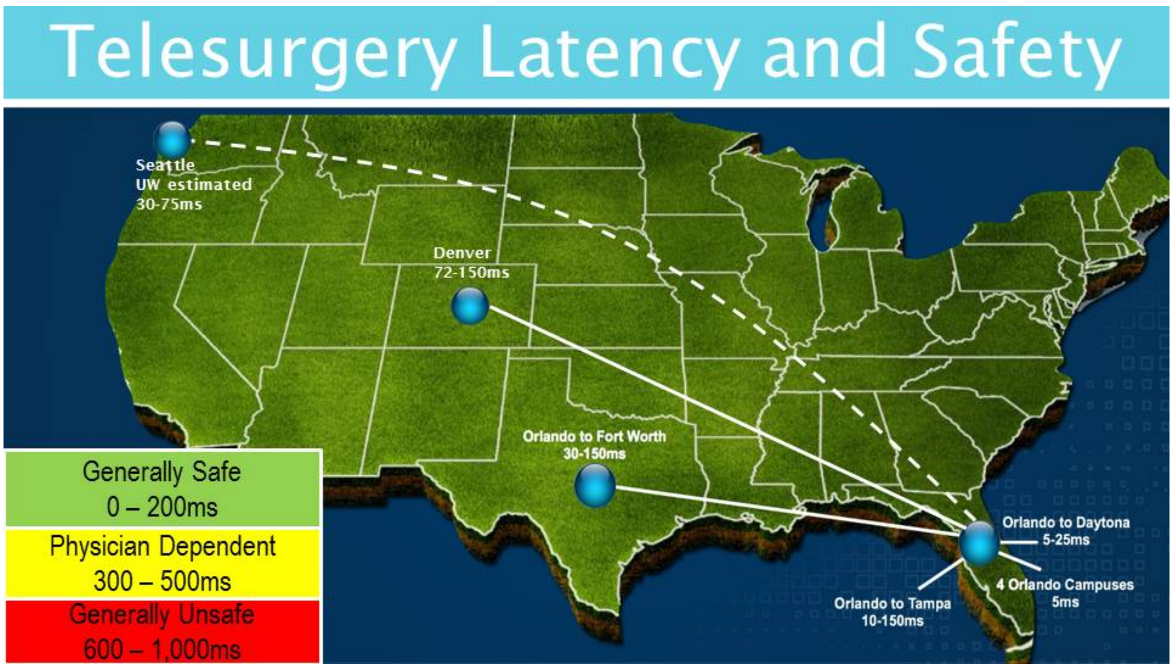




Telesurgery.

Orlando-to-Seattle. Working with the surgical robotics team at University of Washington, led by Dr. Blake Hannaford, we were able to use existing experiments performed by UW to estimate the probable latency between the two sites. Based on this previously performed and published work, we estimate the latency to fall between 30ms and 75ms.

When compared with the data collected to Denver and Fort Worth, the Seattle estimate appears to be more aggressive or optimistic. We believe this is driven by two factors. UW's experiments were performed using the UW Raven robotic device and represent video data of a lower resolution. This could easily account for the differences in the results.



Key Research Accomplishments

- *Telesurgery: Communications Latency*. Major hospital systems have sufficient telecommunication bandwidth to perform robotic telesurgery right now.
- *Surgical Rehearsal.* Simulation-based training for different forms of robotic procedures appears to be feasible beyond the simulators of the da Vinci robot which have previously been created. These could be applied to systems like the Mazor Renaissance spinal robotic system and the Mako Rio orthopedic robotic system.
- Multiple publications and presentations have been generated from this research work.

Reportable Outcomes

(since September 2015 only)

Publications

1. Julian, Tanaka, Mattingly, Perez, Truong, Simpson, Smith. "Comparative Analysis of Four Simulators of the da Vinci Surgical Robot", *Surgical Endoscopy*, (Under review).

2. Smith, Tanaka, Julian, Mattingly. (Dec 2016). "Blended Training for Surgeon Education." *2016 Interservice/Industry Training Education and Simulation (I/ITSEC) Conference*.

3. Julian, Tanaka, Mattingly, Smith. (Dec 2016). "Surgical Simulator Showdown." *2016 Interservice/Industry Training Education and Simulation (I/ITSEC) Conference*.

4. Tanaka, Julian, Mattingly, Smith. (Dec 2016). "Validation for Simulators: It's All About Perspective." *2016 Interservice/Industry Training Education and Simulation (I/ITSEC) Conference*.

5. Smith R. "Response to Unlike History, Should a Simulator Not Repeat Itself?" *Simulation in Healthcare*, 11(3).

6. Mouraviev et al. "Robotic training with porcine models induces less workload than virtual reality robotic simulators for urology resident trainees" *Journal of the AUA* and AUA Annual Congress, Dec 2015

7. Smith, Tanaka, McIllwain, Willson. (Dec 2015). "Developing Game-based Leadership Training for Robotic Surgeons." *2015 Interservice/Industry Training Education and Simulation (I/ITSEC) Conference*.

8. Tanaka, Graddy, Smith, Perez. (Dec 2015). "Gamers Today, Surgeons Tomorrow?" *2015 Interservice/Industry Training Education and Simulation (I/ITSEC) Conference*.

9. Tanaka, Graddy, Simpson, Perez, Truong, & Smith. (Accepted). "Robotic Surgery Simulation Validity and Usability Comparative Analysis". *Journal of Surgical Endoscopy*.

Presentations

1. Mattingly, Tanaka, Julian, Smith. (Nov 2016). "Virtual Reality Robotic Simulation Performance Assessment: Simulator Metrics vs. GEARS." Annual Meeting of the American Association of Gynecologic Laparoscopists.

2. Mattingly, Tanaka, Julian, Skinner, Smith. (Nov 2016). "Simulator-based Multi-modal Task Decomposition of Robotic Surgical Technique for Vaginal Cuff Closure." Annual Meeting of the American Association of Gynecologic Laparoscopists.

3. Tanaka, Smith. “Searching for Cognitive Ergonomics in Surgical Education”, International Meeting on Human Factors and Ergonomics, June, 2016.

4. Smith R. “R&D in Robotic Surgery Devices”, Annual Meeting of the Industrial Research Institute, May 2016.

5. Smith, “Robots in Surgery and Simulation in Training.” IEEE International Systems Conference, April 2016.

6. Julian, Tanaka, Smith, “A Side-by-Side Comparison of Virtual Reality Robotic Surgical Simulators.” Florida Hospital Research Conference, April 2016.

7. Tanaka, Smith, Hughes, “Video Game Experience and Basic Robotic Skills.” IEEE International Conference on Serious Games and Applications for Health, February 2016.

8. Smith R. “The Validation of Surgical Simulators for RASD”. FDA Workshop on Robotically Assisted Surgical Devices, Washington DC, August 2015.

9. Tanaka, Graddy, Perez, Simpson, Truong, Smith. (Nov 2015). “Video Game Impact on Basic Robotic Surgical Skills.” Annual Meeting of the American Association of Gynecologic Laparoscopists.

10. Perez, Tanaka, Simpson, Truong, Smith, Satava. (Nov 2015). “From concept to surgical relevance: Engineering the training device for the Fundamentals of Robotic Surgery.” Annual Meeting of the American Association of Gynecologic Laparoscopists.

Poster Presentations

1. Julian, D., Tanaka, A., Mattingly, P., & Smith, R. (2016). “A Side-by-Side Comparison of Virtual Reality Robotic Surgical Simulators.” University of Central Florida Graduate Research Forum 2016. Orlando, Fl.

2. Tanaka, Graddy, Perez, Simpson, Truong, Smith. (Jan 2016). “Video Game Impact on Basic Robotic Surgical Skills.” International Meeting on Simulation in Healthcare, San Diego, CA.

Conclusion

Each of the research areas funded by this grant has made significant scientific contributions. The knowledge gained from this work is being shared through reports to the government and multiple presentations at both clinical and simulation conferences. We have also submitted multiple papers for journal publication.

This cooperative agreement is scheduled to end on February 28, 2017. Based on our current work flow and state of funds the project is currently on schedule to complete all objectives by the end of the agreement.

Appendices

Copies of manuscripts, abstracts, and presentations of work resulting from this grant are included as appendices to this report.

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.

Developing Game-based Leadership Training for Robotic Surgeons

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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.

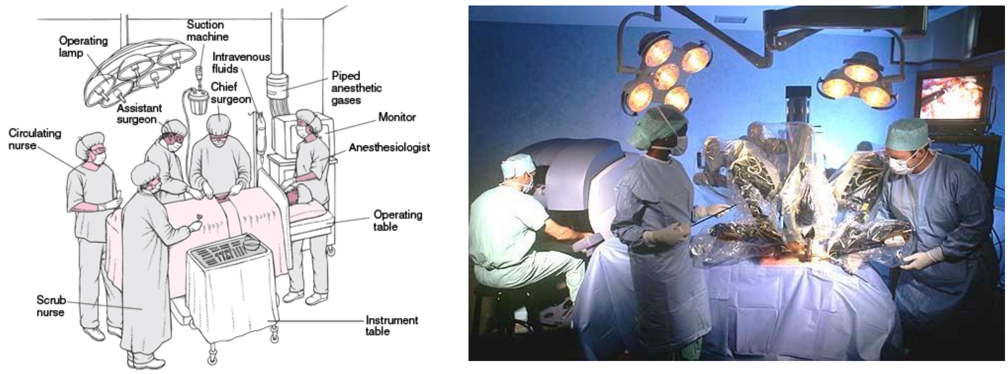

Figure 1. Traditional vs. Robotic OR Team Positions.

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.

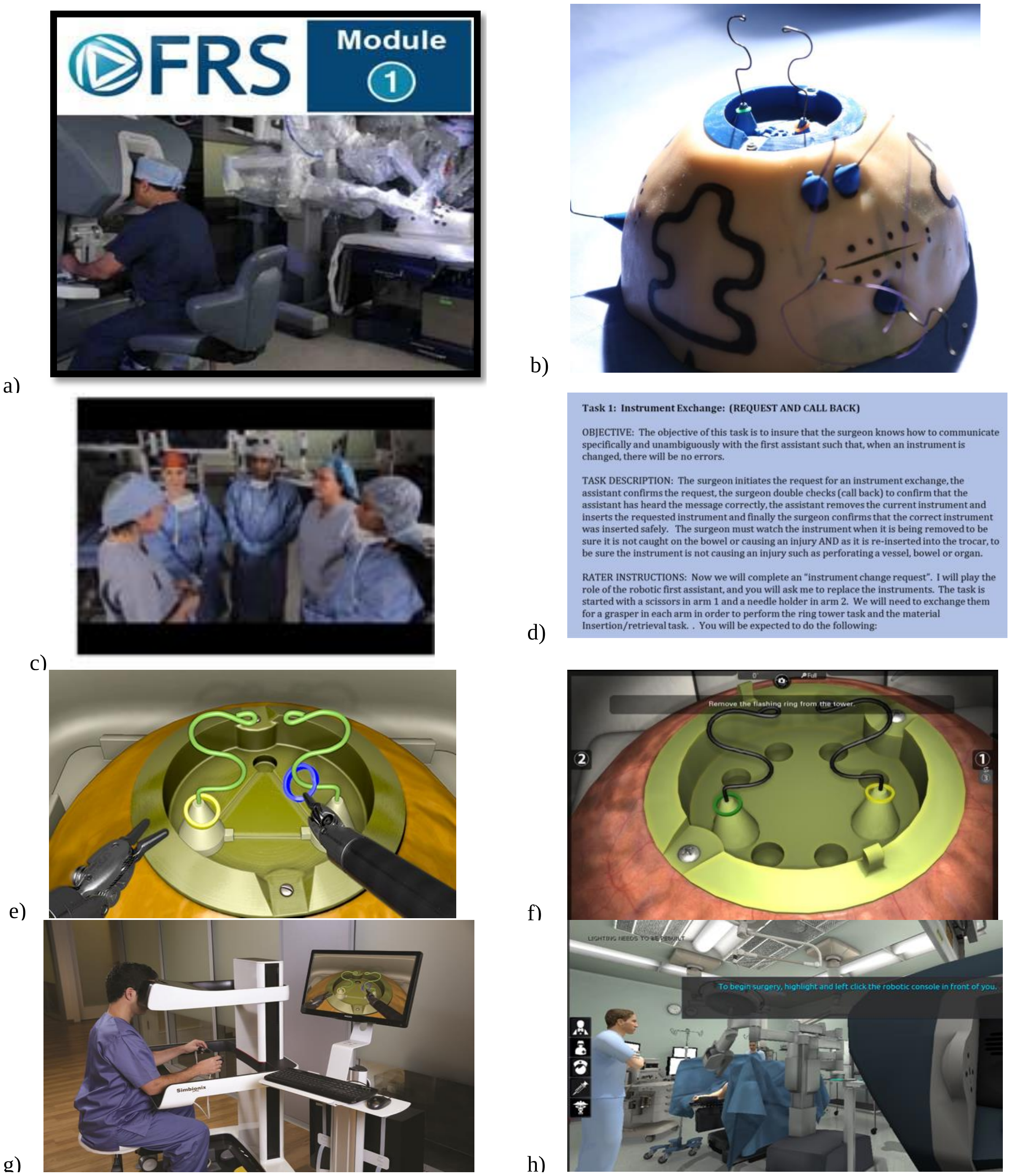

Figure 2. Fundamentals of Robotic Surgery Curriculum Products – (a) online curriculum, (b) psychomotor skills device, (c) team training videos, (d) role playing script, (e) Intuitive DVSS simulator, (f) Mimic dV-Trainer simulator, (g) Simbionix Robotix Mentor simulator, (h) RoboTeamView virtual world.

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.

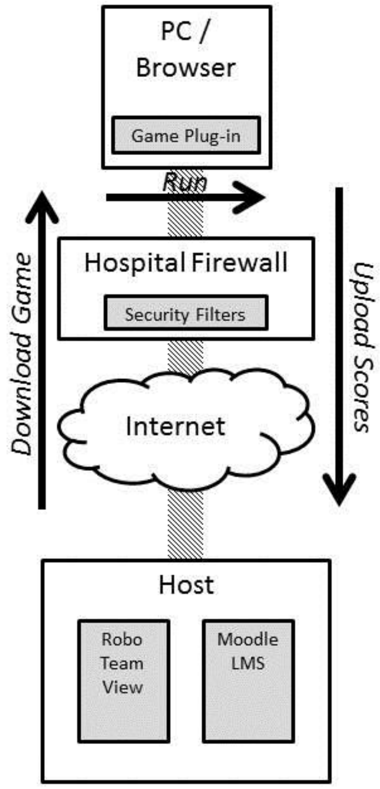

Figure 4. RoboTeamView System and Network Architecture

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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Gamers Today, Surgeons Tomorrow?

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ABSTRACT

Faced with an age of reliance on technology and innovative advances, surgeons are using cutting-edge robotic systems to perform complex procedures and virtual reality simulators for specialized skill training. The virtual environment and controllers in surgical simulators are reminiscent of those in videogames. So, can playing video games develop skills similar to those used in robotic surgery?

This paper compares the performance of video gamers, medical students, and "lay people" to expert robotic surgeons on a robotic surgery simulator. Participants recruited from the UCF College of Medicine, UCF FIEA, and Florida Hospital completed a demographic questionnaire. The subjects then performed three computer-based perceptual tests and participated in two warm-up tasks on the Mimic dV-Trainer to familiarize themselves with the system. The experiment then measured their performance over eight trials of two core simulated exercises. After completing these trials, participants completed a post-questionnaire about their experience.

Analysis of the data did not verify differences between the groups for the perceptual tests except for the time to complete scores in the Flanker and subsidizing tasks, in which expert surgeons took significantly longer than other groups. Significant differences were found between the groups for the first and eighth trials of the simulated exercises, with surgeons performing better than other groups. All groups improved significantly from trial one to trial eight, with surgeons performing better than all groups. Gaming console type positively correlated with Overall Score in the Ring & Rail exercise, as well as Time and Economy of Motion in the suturing exercise. No other correlations were found.

The results are in contrast with prior literature on video game experience in laparoscopic surgery, suggesting that gaming abilities do not translate to all surgical modalities. Future research is necessary to further examine the impact alternative skillsets may have on surgical skills.

ABOUT THE AUTHORS

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System where she aided in the development of employee education materials and program planning and evaluation with the Geriatric Research Education and Clinical Center. She holds a Bachelors of Science in Health Education from the University of Florida and a Masters of Health Administration from the University of South Florida.

Manuela Perez, M.D., Ph.D. is a practicing General Surgeon at the University Hospital of Nancy-France, where she also serves as an Assistant Professor in General Surgery and Anatomy. Dr. Perez has been practicing medicine for 14 years and graduated with her PhD in Robotic Surgery, with a thesis entitled "Telesurgery: From Training to Implementation." Currently, she is working as a Research Fellow at the Florida Hospital Nicholson Center and working under a grant from the Department of Defense researching various aspects of Telesurgery.

Roger Smith, Ph.D. 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.

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INTRODUCTION

Surgery is generally described as fitting into one of two modalities—open and minimally invasive, the latter of which includes laparoscopic and robotic-assisted (i.e. robotic surgery) procedures. Robotic surgery, the most recent iteration of laparoscopy, typically implies that the surgeon's movements are facilitated through a computer driven system to manipulate surgical tools. This field evolved from the prospect of surgeons performing life saving procedures on soldiers in combat zones from remote locations anywhere in the world, an application referred to as telesurgery.

This concept has not completely come to fruition, however the fundamental research resulted in the commercial the daVinci Surgical System that is now used to perform everyday procedures in urologic, gynecologic, ENT, and general surgery specialties called (Barbash, Friedman, Glied, & Steiner, 2014; Serati et al., 2014; Maan, Gibbins, Al-Jabri, & D'Souza, 2012; Luca et al., 2013; Zureikat et al., 2013). The surgeon manipulates controllers at the surgeon console to manage up to four robotic arms, including a camera, attached to a separate patient cart. The camera provides true stereoscopic vision to the surgeon, facilitating a synthetic tactile sensation and depth perception. Attached to the other robotic arms are various instruments, which move in a similar manner as the surgeon's hands (Figure 1).

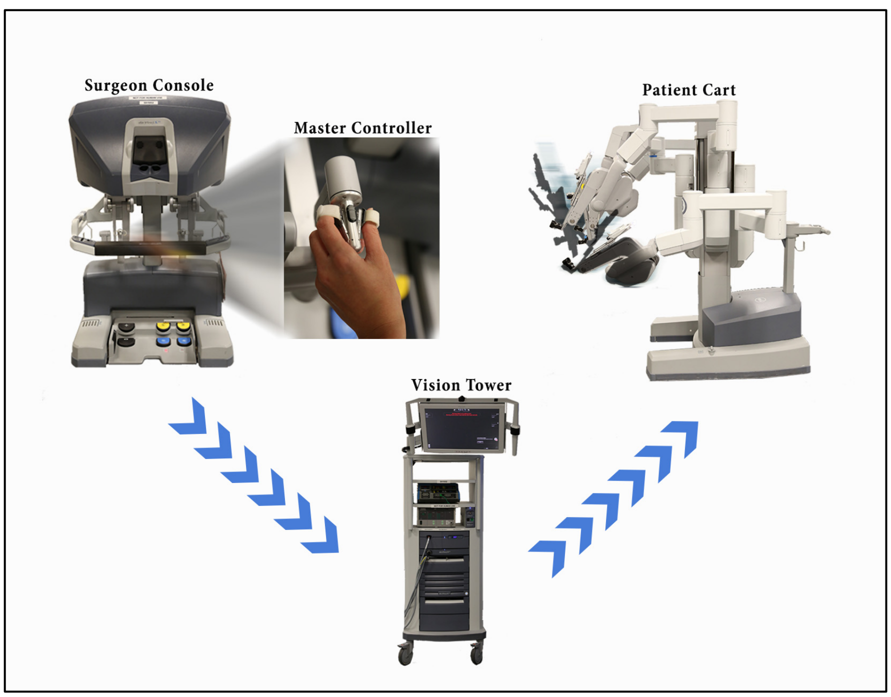

Figure 1. The daVinci System

While this system integrates robotics into medicine in a way that may seem more science fiction than reality, society is actually connecting with technology in unforeseen ways. Traditional surgical skills are being transcended by cutting-edge technologies, which require surgeons to possess distinct skill sets from those of the past and which overcome a learning curve to acquire the technical (i.e. psychomotor) skills associated with using the daVinci system. Efforts have focused on developing specialized curricula for the training of such skills (e.g. the Fundamentals of Robotic Surgery and Robotic Training Network), but can learning curves be reduced to facilitate a faster acquisition of skills in surgical trainees?

Previous research has established that trainees with video game experience demonstrate increased abilities on basic laparoscopic skill trainings (Rosenthal et al., 2011; Grantcharov, Bardram, Funch-Jensen & Rosenberg, 2003; Rosser et al., 2007). Also, video games have proven to be valuable training tools for basic laparoscopic skills (Rosser, Gentile, Hanigan, & Danner et al., 2012; Badurdeen et al., 2010; Ju, Chang, Buckley, & Wang, 2012; Bokhari et al., 2010; Schlickum, Hedman, Enochsson, Kjellin, & Fellander- Tsai, 2009; Giannotti et al., 2013). Certain genres of video games have established effects on perceptual skills similar to those required by robotic surgeons, yet few have attempted to make a connection between video game experience and robotic surgical skills (Green & Bavelier, 2012; Green & Bavelier, 2007; Chien et al., 2013; Harper et al., 2007).

Thus, this research aims to examine the performance of experienced video gamers while using a robotic surgery simulator, and compare the performance of this population with experienced robotic surgeons, medical students, and laypeople. The purpose is to determine the effect that video game usage may have on the perceptual abilities that are used for robotic surgery. Contrary to previous research that used surgical trainees with minimal gaming experience, this research aimed to utilize subjects with high levels of gaming experience and compare their abilities to subjects with different levels of expertise. This study also looks at the groups' ability to acquire basic surgical skills using the simulator.

METHODS

Recruitment

Participants in this study included video game experts (VGEs), expert robotic surgeons, medical students, and "laypeople" (i.e. individuals without formal medical education or extensive gaming experience). VGEs were recruited from a local university offering degrees specializing in game design and development (i.e. Florida Interactive and Entertainment Academy [FIEA]). Potential VGE subjects were required to be enrolled in a game design program and self-report daily videogame play of at least two hours per day, five days per week. Expert robotic surgeons were recruited from Florida Hospital, Florida Hospital Nicholson Center training courses, and at relevant surgical conferences. These individuals were practicing physicians and self-report performing at least 100 robotic surgical procedures, of which he or she performed at least 50% of the procedure on the surgical console. Medical students were recruited from the University of Central Florida College of Medicine (UCF CoM) and laypeople were recruited from all data collection sites. Potential subjects were excluded from the study in the case of having experience in more than one participant category (e.g. a medical student or expert robotic surgeon who engages in regular gameplay of more than two hours per week).

Materials

All subjects completed a pre-questionnaire, which gathered demographic information (e.g., age, gender, handedness, hours of weekly gameplay, number of robotic cases). The participants then performed three computer-based perceptual tests: a Flanker compatibility task, a subsidizing task, and a Multiple Object Tracking (MOT) test. The Flanker compatibility test requires the participant to indicate the orientation of a single arrow in the center of a group of several other arrows. The arrows are randomly generated to all face the same orientation (congruent) or face the opposite direction of the target arrow in the center (incongruent). This tests attentional capacity by requiring the subject to focus solely on the relevant arrow and ignoring other stimuli. The subsidizing task also assesses attentional capacity by requiring subjects to identify the number of dots that appear on the screen by pressing the associated number key. In the MOT task, users must track specific objects while they move across the screen with other identical objects, which assesses visual attention (Figure 2).

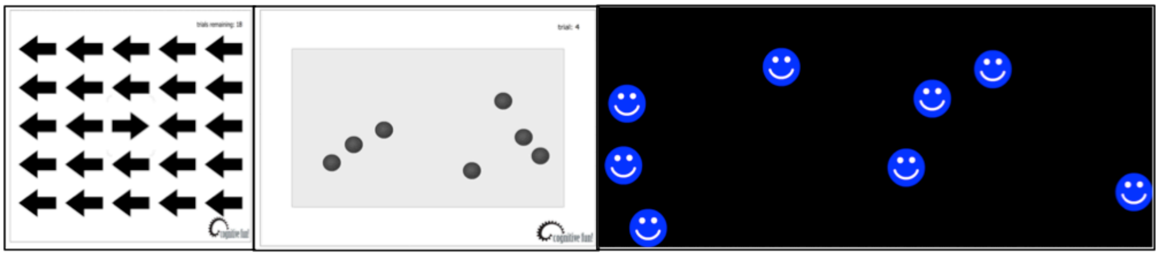

Figure 2. Examples of the Flanker, subsidizing, and MOT tasks

Participants then performed two warm-up exercises on the Mimic dV-Trainer, Pick & Place and Basic Camera Targeting, to familiarize themselves with the system and system controls. All subjects then performed eight trials of two core exercises to test various basic skills (Table 1). Ring & Rail 1 and Suture Sponge 1 will serve as the primary exercises for data collection. After completing all exercises on the dV-Trainer, specific metrics are shown to the participants: Overall Score, Economy of Motion, Time to Complete, Excessive Instrument Force, Instruments Out of View, and Master Workspace Range. These primary metrics are exported for each exercise and used with other metrics to form the scoring system.

Table 1. dV-Trainer exercise descriptions

Exercise	Purpose	Objective	Skills Trained
Warm-up Exercises			
Pick & Place	Introduction to using stereo vision and EndoWrist instruments for picking up and placing objects.	Place colored objects in matching colored containers.	Endowrist Manipulation
Basic Camera Targeting	Learn to accurately position the camera while working in a large workspace while practicing to keep the instruments in view and developing stereo depth acuity.	Manipulate the camera to position light blue sphere camera targets in the center of your screen's dark blue crosshairs.	Camera Control
Core Exercises			
Ring & Rail 1	Coordinate control of an object's position and orientation along a trajectory using the EndoWrist instruments	Pick up a ring and guide the ring along a curved rail	Endowrist manipulation, Camera Control
Basic Suture Sponge	Improve dexterity and accuracy when driving a needle through a deformable object.	Insert and extract a needle through several targets on the edge of a sponge with random variations in their positions.	Endowrist manipulation, Camera Control, Needle Control, Needle Driving

After completing all trials, participants completed a post-questionnaire regarding their experience with the system (Figure 3).

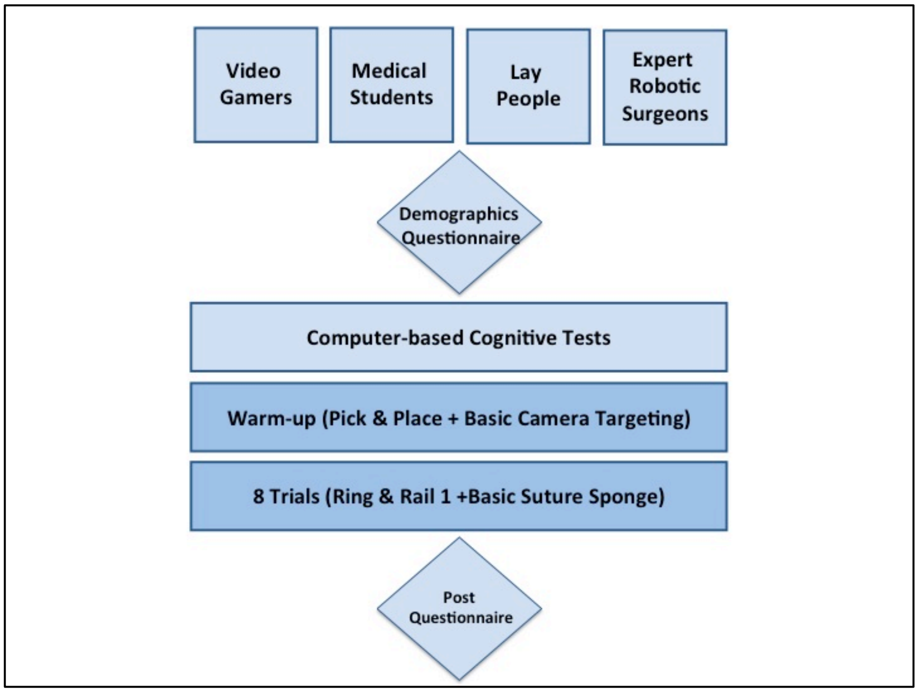

Figure 3. Order of study procedures

RESULTS

Demographics

Table 2 shows descriptive characteristics of the participants. Gamers indicated playing on average 11.71 hours of video games per week and having 17.85 years of gaming experience. On average, expert robotic surgeons performed 503 total robotic cases and 127 cases per year. While none of the expert surgeons reported currently playing video games, 29% indicated playing video games in the past. Thirty-three percent of lay people also indicated playing video games in the past.

Table 2. Descriptive Statistics

Descriptive Statistics				
	Gamers	Medical Students	Laypeople	Experts
n=	40	24	42	7
Age	25.38	25.63	29.45	42
Male	77.5%	70.83%	52.38%	71.43%
Female	22.5%	29.17%	47.62%	28.57%
Right Handed	87.50%	95.83%	83.33%	100%
Left Handed	12.50%	4.17%	16.67%	0%

Cognitive Tests

For the Flanker and the subsidizing tasks, an ANOVA was performed to compare the four groups in terms of percent of correct responses and average response time (ms) for incongruent and congruent arrows. No statistical differences were found for the percent correct for the Flanker test, however completion times for the congruent and incongruent representations were significantly different between the groups (Congruent $p<0.005$; Incongruent $p=0.007$). Expert robotic surgeons took longer in both instances to perform the tasks.

No significant differences were found for the percent correct on the subsidizing task for any groups. Similarly to the Flanker test, completion times were significantly different between the groups ($p=0.001$), with expert surgeons performing slower than the other groups. The MOT test was analyzed using a nonparametric test to compare the number of correct responses. No significant differences were found for any groups for the MOT test.

The cognitive scores were also analyzed in terms of certain demographic responses to determine if an association exists between the demographic characteristics and the cognitive test scores. A Pearson correlation coefficient was calculated. The characteristic of age positively correlated with the Flanker Time ($p=0.008$) and Flanker Incongruent Time ($p<0.005$). Age negatively correlated with the hours of weekly video game play ($p=0.010$). Age was also negatively correlated with the number of correct responses in the normal level of difficulty MOT task ($p<0.001$).

Simulator Scores

The simulator scores were analyzed in terms of three performance metrics for both simulated exercises: Overall Score, Economy of Motion, and Time to Complete. Overall Score is a composite score comprised of multiple performance metrics, including Economy of Motion and Time to Complete. Economy of motion is the total distance that the instrument tips moved and is measured in centimeters. Time to Complete is the total number of seconds required by the user to perform the exercise.

An ANOVA was used to determine if differences existed between the groups for the first (i.e. Trial 1) and the last (i.e. Trial 8) of the Ring & Rail 1 and Suture Sponge for the performance metrics. The groups performed significantly different for the performance metrics for trial 1 in both exercises except for the Overall Score of Ring & Rail. Using a Least Significant Difference Test, experts performed significantly better than other groups for the metrics. Similar results were found for trial 8 of both exercises. Experts again performed significantly better than all groups in trial 8 for both exercises scores all metrics (Table 3).

Table 3. Differences in simulator scores for Trial 1 and Trial 8

Trial 1		**Trial 8**	
Ring & Rail 1			
Overall Score	$p=0.086$	**Overall Score**	$p=0.256$
Economy of Motion	$p<0.05$	**Economy of Motion**	$p<0.005$
Time	$p<0.005$	**Time**	$p<0.005$
Suture Sponge			
Overall Score	$p<0.001$	**Overall Score**	$p<0.05$
Economy of Motion	$p<0.005$	**Economy of Motion**	$p<0.005$
Time	$p<0.001$	**Time**	$p<0.001$

The simulator performances were also analyzed using an ANOVA to determine if differences exist between the groups in terms of the change in performance from trial 1 to trial 8 for both exercises separately. A difference existed in the average Overall Score and Economy of Motion metrics from trial 1 to trial 8 for all groups in the Ring & Rail 1 exercise (Overall Score $p<0.001$; Economy of Motion $p<0.001$). Experts were found to be significantly different from the other groups for both metrics (Overall Score $p=0.045$; Economy of Motion $p=0.002$). A significant interaction was found between the trials and the groups for the Time metrics ($p=0.006$). The main effects of the trials were not examined due to this interaction.

A difference existed in the average Overall Score and the Economy of Motion metrics from trial 1 to trial 8 for all groups in the Suture Sponge exercise (Overall score $p<0.001$; Economy of Motion $p<0.001$). Experts were also found to be significantly different from the other groups for both metrics (Overall Score $p<0.001$; Economy of Motion $p<0.001$). A significant interaction was found between the trials and the groups for the Time metric ($p=0.011$). The main effects of the trials were not examined due to this interaction. The average of each metric across the eight trials for each exercise can be seen in Figure 4 and Figure 5.

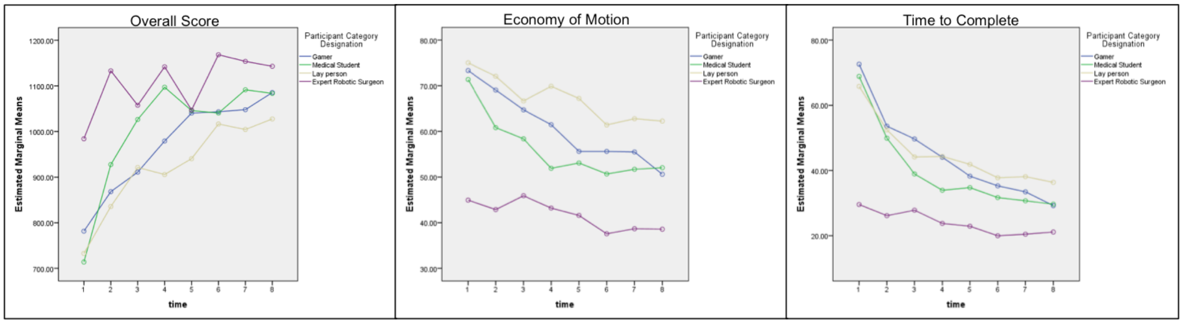

Figure 4. Average scores for groups across eight trials of Ring & Rail 1

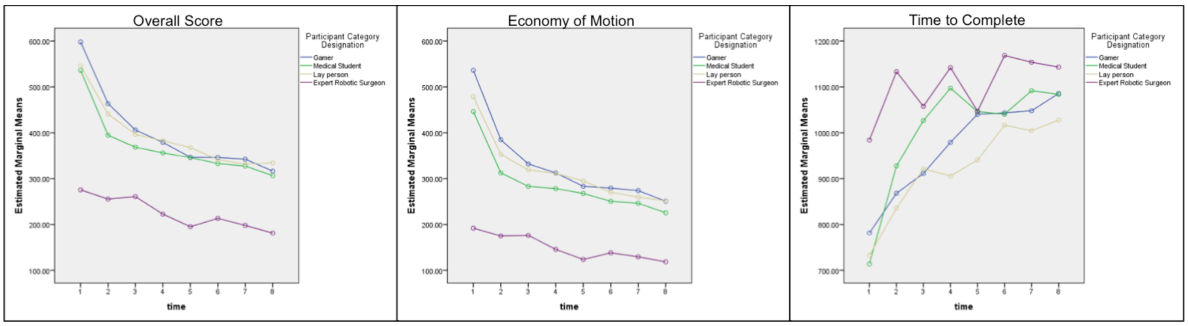

Figure 5. Average scores for groups across eight trials of Suture Sponge

An analysis was conducted to determine if an association existed between the perceptual test scores and the simulator metrics for the two exercises. The Flanker scores for the percent of correct responses negatively correlated with time to complete for the Ring and Rail 1 exercise (p=0.006). This suggests that as the correct response percentage increased the time taken to complete the exercise decreased. No other Ring & Rail 1 metrics correlated with the perceptual tests. No associations were found between the Suture Sponge scores and the perceptual test scores. The subsidizing and MOT task scores were not significantly correlated with any metric values for Ring and Rail 1 or Suture Sponge.

Video Games

The video game experience of the subjects was also analyzed to determine if certain aspects of video game play were associated with simulation scores. For this analysis the type of game and console played by the subjects was used. The game type ranged from not using videogames, playing slow-paced strategy games (e.g. puzzle games), playing both types of games, or playing fast-paced action games (e.g. first person shooters). The console type ranged from not playing video games, using a controller with minimal hand movement (e.g. Playstation4), using all controller types, or using a controller that may require larger movements (e.g. Wii).

No significant correlations were found between the type of video game or console played and the performance metrics for either exercise for trial 1. A significant positive correlation for Overall Score and the type of console was found for trial 8 of Ring and Rail 1 (p=0.049). This association suggests that as the movement to control the game increased, the Overall Score increased. A significant positive correlation was found between the type of console and Economy of Motion and Time for trial 8 of Suture Sponge (Economy of Motion p=0.044; Time to Complete p=0.002). This suggests that as the movement to control the video game increased, the time to complete and the distance traveled by the instrument tips increased (i.e. slower and less efficient with movements).

DISCUSSION

The assumption that video gamers will perform better than others using a virtual reality robotic surgery simulator is very common. The manipulation of the hand controls and the users interaction with the synthetic environment seem comparable to that of a video game. Contrary to these similarities and prior literature in laparoscopy, video gamers in this study did not perform better than other groups including the "Average Joe" in a robotic surgery simulator. The results did suggest that subjects who use higher movement game controllers (i.e. Ninetendo Wii) scored higher in the Ring & Rail 1 exercise. However, those individuals also took longer and were less efficient with their movements in the Suturing exercise.

The results from this study align with the few studies that have examined the impact of video game play on robotic surgical skills. Chien et al. (2013) found that in comparison to a group using task specific virtual reality training, a control group using video game training did not perform as well on an actual task using the surgical robot. The authors also found that using a video game to train actually had a negative impact on the post-training performance. Harper et al. (2007) found that video game players tied significantly fewer knots using the surgical robot and also suggest that video games may have a negative impact on surgical skills.

Why does prior video game experience impact basic laparoscopic skills, but not robotic? Differences may be contributed to the distinctness of the systems that the users are interacting. The skills developed in two-dimension video games may transfer more appropriately to laparoscopic surgery, which uses a two-dimensional screen, as opposed to the three-dimensional view in robotics. Laparoscopy involves contrasting movements to the primarily fine motor movements of robotic surgery and it is possible that gamers are more inclined with the manual dexterity associated with laparoscopy.

While this study was unable to validate enhanced abilities of video gamers in robotic surgery, the results demonstrated that the effect video game play has on surgical skills is nuanced by the surgical technique. In a technologically dependent society where video games have become an integral past time, this analysis of skills will likely become more valuable as other fields leverage the gaming generation's experience into training. The findings can be generalized to domains outside of medicine utilizing robotic and computer-controlled systems (e.g. unmanned vehicle operation), speaking to the scope of the gamers' abilities and pointing to the capacity within these systems.

Future research should examine the impact alternative skillsets may have on a user's abilities in a robotic surgery system (e.g. playing sports). The gamers in this study did not perform significantly better than lay people, which may imply that other factors or hobbies contributed to the performance. Only one surgical robot currently exists, however others have realized the technological advances and future iterations of surgical robotic systems are imminent. As these new technologies enter the market, it will be critical to evaluate how these skillsets may be valuable to the field of robotic surgery.

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Blended Training for Surgeon Education

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ABSTRACT

Complexity in surgery lies at the crossroad between the complexity of the human body and the capabilities of the surgical tools available. While we continue to improve our understanding of the body, we are also inventing new tools to address and correct issues through surgery. As a result, the complexity of surgery is expanding on two fronts simultaneously. This creates a lifetime learning environment for practitioners and a challenge for the systems which educate, measure, certify, regulate, and privilege surgeons. The models of training in this field are slow to evolve and still rest on a foundation of lecture and hands-on practice which has changed little in 100 years. Surgeons largely believe that real hands-on practice with human tissue – excised organs, cadavers, and live patients – is the most effective form of training. But it is also the most expensive, difficult to facilitate, and least accessible form.

The emergence and maturation of the concept of blended learning in public and military education may prove equally valuable in surgical education and training. Creating a learner-centric environment in which multiple modes of education are encouraged, available, integrated, and accredited can potentially increase the level of competence of new surgeons, maintain competence in practicing surgeons, and provide objective metrics to the public and hospital systems.

This paper defines a framework for blended surgical training using principles developed for the military. This framework includes knowledge and skills-based training in both an individual and a group learning environment which includes distance and e-learning sessions, face-to-face engagements, laboratory events, and operating room experiences as modes of surgical education that are not integrated into a coherent program with defined metrics. The goal of the framework is to apply blended learning principles to the surgical education and training community, with reference to prior activities in public and military education.

Keywords: blended learning, learning science, surgical training, medical education

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NATURE OF SURGICAL EDUCATION

Developing the ability to perform surgical procedures requires mastering complexity in multiple dimensions. It calls for cognitive knowledge, psychomotor skills, and team management techniques. Mature attending surgeons must be competent in all of these to lead a surgical team through a procedure in which a patient's health and life are at risk. Accomplishing all of this has led to extensively long educational programs which typically include a four year bachelor degree, a four year medical degree, a three to five year residency, and perhaps a two year fellowship. But in many countries, safety regulations have limited the number of hours that a resident or fellow can learn and practice during this process (Funke, 2013). At the same time, the explosion of medical tools and technologies has led to ever increasing numbers of available procedures and the specialized knowledge that accompanies these. Acquiring more knowledge and skills by increasing the number of practice hours is not possible, so one alternative is to improve the methods of education, hopefully increasing the speed at which mastery can be attained through more efficient educational methods.

Beyond the formal educational programs, practicing surgeons are also constantly acquiring new skills through continuing medical education (CME) courses. These provide knowledge, skills, and team management for a new procedure, tool, or technique in a one or two day event. The degree to which this material is mastered is based, not just on the quality of the instructor and the intelligence of the student, but also on the instructional methods that are applied and the tools which are used to transfer knowledge and skills. Instructors for these courses typically prepare traditional slide presentations, videos of procedures and tools, and hands-on laboratory sessions with tools and tissue. Assessment of performance and skill acquisition is usually based on subjective instructor observation and quantitative scores on exams. But these courses typically lack an objective metric for the acquisition of psychomotor or team management skills. Educators search for additional tools and methods that can provide accurate assessments of performance in these compressed events.

Medical education from CME to under graduate medical school has always attempted to blend books, hands-on labs, apprenticeships, and research (Cooke, 2010). This model has been created, but its implementation is different at every institution based on faculty abilities, facilities available, patient presentation, scheduling, and other factors. This results in a wide variation of effectiveness and the emergence of a rumor-based reputation of the quality of each program. Nissen (2015) has recently published his view that CME in particular is not effective at improving surgeon performance or patient outcomes. He maintains that the CME system of education as a whole needs to be reformed, a major criticism of the current practice.

BLENDED LEARNING

While medical and surgical educators search for effective teaching methods and tools, the public schools have been actively developing concepts labeled as "blended learning" (Bonk, 2006; Horn and Straker, 2015). In its current form, this focuses on the integration of in-class, lecture-based instruction with electronic, online, independent educational materials. Horn and Straker (2015) have explicitly identified four dominant models of blended learning that are in use in America's classrooms. These include – the rotation model, flex model, a la carte model, and enriched virtual model. Each of these represents a different sequencing or emphasis of learning via teacher-led instruction, collaborative activities, and online instruction. Given the estimated $60 billion investment in computers for classrooms (Christensen, 2011) the emphasis has been on how to add value equivalent to this enormous investment in basic technology.

Popular definitions of blended learning focus on this public school environment.

> "Blended learning is a formal education program in which a student learns at least in part through delivery of content and instruction via digital and online media with some element of student control over time, place, path, or pace. While still attending a 'brick-and-mortar' school structure, face-to-face classroom methods are combined with computer-mediated activities." (Horn and Straker, 2015)

This is certainly one important environment. But the structure and limitations of the K-12 classroom are not necessarily appropriate for other environments. Throughout these two books there is an emphasis on control of immature students and assessment via tests which indicate whether the student should progress. But there is little consideration for adult learning in which assessment can take more interactive and dynamic forms, such as demonstrated performance of skills. McCafferty and Desaulniers (2004), Fautua et al (2014), and Schatz et al (2015) have all explored what blended learning can contribute to military training programs. Their work and lessons learned appear to be much more similar to adult medical and surgical training than the K-12 educational texts on blended learning.

But a more appropriate and useful definition is something similar to that quoted from Michael Orey in McCafferty (2004):

> "Blended learning is the ability to choose among all available facilities, technology, media, and materials matching those that apply to my prior knowledge and style of learning as I deem appropriate to achieve instructional goals."

This definition is much more encompassing of all learning tools and methods available. It also seems to capture an active role on the part of the student, rather than treating the student as a passive agent to be acted upon by the teaching system. Peder Jacobsen cites a US Department of Labor study which estimates that 70% or more of all learning occurs on the job, not in a structured classroom or educational environment. This means that traditional educators and formal education materials are only able to impact 30% of the learning experience. This calls for both effective methods for impacting that limited volume of experience and a search for methods which can become part of the majority 70% that is happening in other environments (Saltzman, 2010).

Military training organizations have adopted the terms "Live, Virtual, and Constructive" to refer to different modes, objectives, and methods of simulation-based training. These terms came into popular use in the late 1990's to describe the literal situation that existed at that time. Training events could be defined as purely Live, or Virtual, or Constructive, lacking the technology and experience to integrate any two of these together. Today the terms have merged into the "LVC" acronym which indicates that we have arrived at a state of blended training in which all three are generally included in any simulation-based training event of significant size. This evolution has relied on improvements in computer and networking technology, but also on the expertise of scientists and engineers who have developed an understanding of how to bring these together. Accomplishing this in an educationally effective manner has been a different and slower process to emerge. The blending of technologies together may have been accomplished without an understanding of how the resulting product would be used, so lacking capabilities that would be essential for effective learning events. Similar challenges exist when attempting to blend simulation into medical education (Gardner, 2015). As a result, educational designers are often faced with a simulation federation which is not well designed to support the needs of the training and education mission. Fautua et al (2014) offered ten recommendations, some of which can be applied to engineering the technology in support of blended learning objectives (Table 1).

Table 1. Fautua's Recommendations for Effective Blended Learning

1. Provide the reason why for goal-oriented adult learners.
2. Gain commitment to the training by trainees and their leaders.
3. Create content which can be reapplied to sustainment training.
4. Focus on the staff being trained, not the canned event.
5. Embed diagnostics which can guide other learning modes.
6. Schedule and plan for remediation.
7. Train the trainers to apply blended concepts.
8. Collect feedback throughout the blend.
9. Emphasize human-system integration.
10. Shift the culture of trainees, trainers, and leaders toward blended approaches.

Each of these represents a very valuable lesson for other subject domains, such as medicine and surgery, and were applied in the development of a blended training framework for surgeons, as presented in this paper. This leads to the need for a larger definition for the term, something more akin to:

> "Learning in the 21st century, especially with adults, requires leveraging all of the information delivery, communication, data collection, and assessment tools that are available. Blended learning may be a useful term to discuss, design, and evaluate learning methods that are very different from those of previous generations, even to the extent of eliminating face-to-face sessions and expert instructors. Perhaps the greatest value in the term 'blended learning' is not in defining it, but in allowing it to undefine the historical approach to education." (Original derivation by the authors for surgical course design.)

SURGICAL BLENDED LEARNING

Just as previous works have applied and expanded blended learning concepts to military education and training, this paper extends those ideas to the field of surgical education. Organizations which offer adult, surgical, continuing education wrestle with many of the same challenges and opportunities as the K-12 and military education systems. But, time is a driving concern when trying to separate practicing surgeons from their daily duties with patients, staff, and hospital administration. Little time is available and each hour that is allocated must provide a return greater than the good which could have been performed in the direct delivery of care.

Adult surgical training programs, often referred to as Continuing Medical Education (CME), generally focus on the hands-on psychomotor skills acquisition through the use of new tools, new techniques, and realistic tissue models. These are excellent learning and practice environments which can be produced only in specialized facilities for a limited number of participants. Blending this core event with other technology-enabled modes of education could potentially deliver knowledge and skills more smoothly, while also improving the learning density of the high-end core event.

Figure 1 illustrates two of the most common pathways for CME in surgery. The traditional path (T) begins when students physically arrive at the training location and assemble as a group in front of the faculty member. This very familiar path is dominated by lecture and typically incorporates photos and vivid videos of surgical performance. It is typified by a one-way flow of information and knowledge. The second step in this path incorporates hands-on laboratory practice with tissue models. The initial focus is on knowledge, which then flows into applying that knowledge to develop specific skills. Students are expected to apply both of these in their surgical practice when leaving the course.

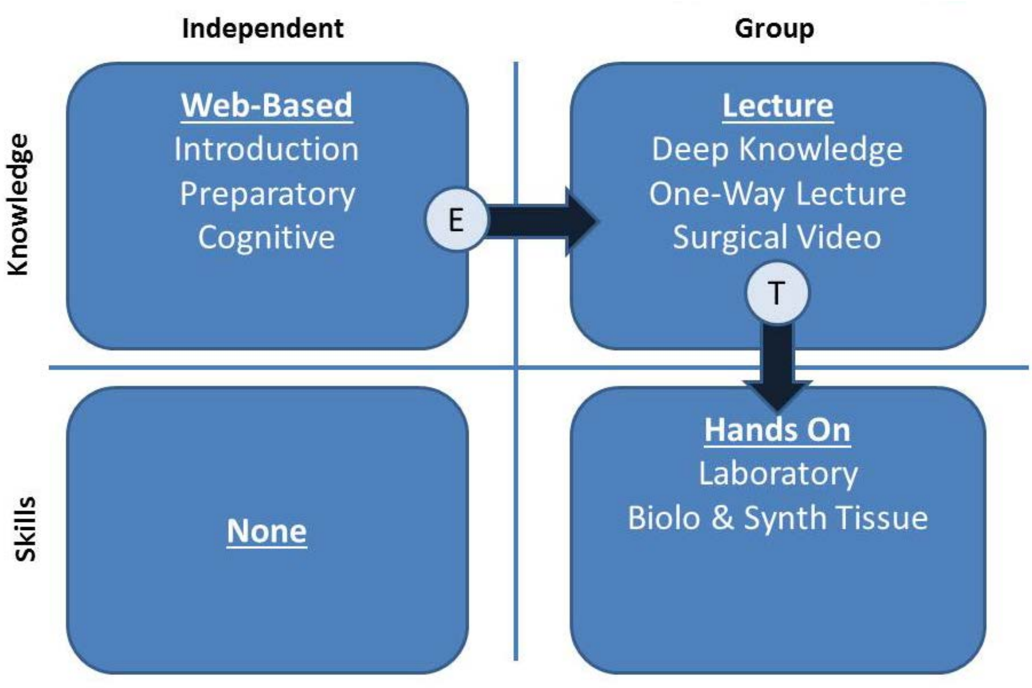

Figure 1. Traditional (T) and Extended (E) Surgical Learning Path for CME

Courses of this type are typically offered in a condensed single or multi-day format. Surgeon-students in most countries can afford to allocate only a few days to attend such a course and are eager to carry what they learn back to their practice.

The second extended (E) pathway enables learners to familiarize themselves with knowledge materials prior to physical assembly at the course. This occurs through online, web-based, internet enabled materials and could rightly be seen as equivalent to the traditional definition of blended learning bridging the internet and the classroom. This mode is expected to either reduce the amount of group time required for the lecture phase of the physical class, or seen as an opportunity to reinforce information by presenting it multiple times in different formats to improve retention. Currently, few or no courses prescribe an independent curriculum of skills exercises prior to physical attendance at a course, though there are opportunities to add this modality.

Experience with hundreds of surgical CME courses indicates that there remains a great deal of opportunity to further extend and enhance the learning pathways which can be applied effectively. Blending methods for surgeons who must learn knowledge, skills, and teamwork calls for a broader view of the blended term and a less linear and standardized version of training for the surgeons. The model shown in Figure 2 illustrates the opportunities that exist with the tools and technologies that are available and experience with directing students through an enriched form of education and training.

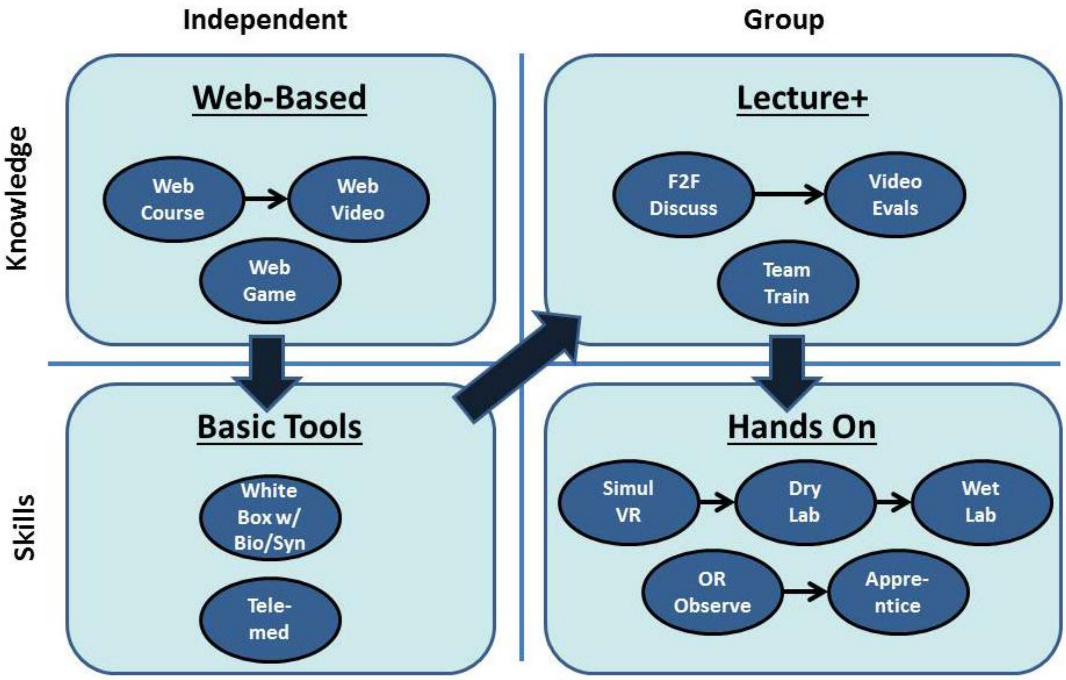

Figure 2. Enriched Blended Learning Environment for Surgical CME

Within this model the two dominant existing learning pathways can still be seen. But they have been enriched internally and extended externally to take advantage of tools and technologies that currently exist, but which are seldom integrated into the learning experience.

Independent-Knowledge

This model begins with independent knowledge acquisition in which each student accesses introductory and case-based materials on their own, typically prior to group events. There are hundreds of online, web-based, case-based courses available today. One huge library of these which focuses on surgical videos can be found at the European WebSurg.com site maintained by IRCAD (Institut de Recherche contre les Cancers de l'Appareil Digestif) in Strasbourg, France. Dozens of training centers, medical device companies, and universities maintain similar, but smaller, online libraries which can be blended into a specific, custom surgical curriculum. These are attractive resources because many medical educators believe that e-learning leads to faster knowledge acquisition and better retention rates (Ruiz, 2006).

More recently, there have been a few game-based learning tools which focus on surgery. These provide a more interactive and dynamic experience which can respond to the learner's actions and provide corrective guidance.

One such tool is the Fundamentals of Robotic Surgery Team Trainer (www.trainrobotic.com) which was designed to guide a surgeon through TeamSTEPPS procedures in a robotic operating room environment.

Independent-Skills

The independent acquisition of basic skills prior to group instruction is not typically part of an instructional curriculum. However, using a number of existing, low cost "box trainers" and inexpensive disposable instruments a surgical student can practice maneuvers which are demonstrated in online course materials. Through centuries of surgical education, a model for the substitution of various grocery meats, excised organs, and animals has evolved to replace practice on live humans. These materials are recognized as acceptable learning environments and many of them are readily available to any learner. More recently, this model has been augmented with an array of synthetic materials which are available from vendors or can be manufactured from silicon compounds.

Telemedicine sessions can also be conducted in which an instructor remotely views the performance of the student and provides customized feedback. Cellphones and laptops are all equipped with the necessary hardware and software to enable this remote, but individualized, instruction. However, this has not yet been integrated into surgical education programs. This mode has the potential to make a significant contribution to student skills prior to group assembly, just as online material is used to build a base level of knowledge prior to a traditional course.

Group-Knowledge

Traditional courses have been very heavy with the dissemination of knowledge materials in a group setting via lecture and videos of actual surgeries. These remain an important part of a blended curriculum because they allow synchronous discussions between students and instructors. But these may also be supplemented with team training role play and table top exercises.

Group learning has typically assumed that all of the participants are physically assembled together for the event. But with the advent of online virtual worlds, it is also possible for group interactions to be facilitated via computer networks. F2F group training may be supplemented with virtual worlds, or the team training may occur prior to the physical meeting, as is accomplished with tools like 3DiTeams (http://www.virtualheroes.com/portfolio/Medical/3DiTeams).

Group-Skills

Surgical training programs are currently most heavily focused on a group setting for skills development. This mode is primarily accomplished with wet and dry lab exercises (biologic and synthetic materials). But it could also include the use of new virtual reality simulators, OR observation, and apprenticeships with an experienced surgeon.

Blending the curriculum between simulators and wet/dry labs has proven to be more difficult than it would first appear. Surgical simulators are faced with computational limitations on representing the behavior of soft tissue and blood flow. These soft features are unique to the human body and have not been previously addressed by either the military simulation or the video game visualization communities. Those domains have made significant improvements in the visualization and physical behaviors of hard, rigid objects like vehicles, terrain, and weapons. But they have done little in the area of tissue flexibility. Even soft objects like clothing and hair have been modeled as rigid objects, rather than tackling the soft fluid behavior problems. Given this situation, surgical simulators typically focus on exercises which develop specific motor skills with simple puzzle environments – e.g. pegs, rings, rails, and simple sponges. This has led to exercises which develop basic, beginner-level skills, but which do not represent the realistic human tissue and blood flow that are necessary for models of real procedures. Funke et al (2013) and other authors maintain that simulators are valuable for younger students, but not for more experienced practitioners who need real patients, partly for this reason. This means that the simulators offer an experience that is similar to simple box trainers, but with more accurate and automated metrics collection. Blending these into a curriculum is difficult to justify when evaluated via a cost/benefits analysis. VR simulators are just beginning to include soft tissue models of procedures with bleeding. As these improve, there will be a unique place for them in many curricula.

OR observation and apprenticeship are a very attractive and popular part of a surgical course. Learning surgeons are eager to see an experienced instructor performing real procedures with human patients and explaining the challenges and rational for each step. This level of realism is difficult to reproduce in wet/dry labs or simulators, so represents a unique learning opportunity which includes real time discussions with the instructor.

Using these four categories as the framework, blending learning content across all available modes yields a surgical education framework as shown in Table 2.

Table 2: Blended Learning Framework with Specific Surgical Content

Independent Knowledge	
Web Course	Introductory knowledge about diagnosis, medical indications, instruments, OR resources, approach to anatomy, legal regulations, and costs. Explain the rich environment and history in which the instrument or procedure exists. Create a common knowledgebase before group events.
Web Video	Introduce the common use of the instrument or the procedure. Present multiple variations and complications that can arise. Organize complications into categories with a shared set of solutions.
Web Game	Create an interactive case-based problem for diagnosis, decision making, and an appreciation for the complexity of the environment and the procedure.
Independent Skills	
White Box	Prescribe skills exercises which can be accomplished independently with accessible and affordable devices and tissue. Encourage rehearsal of common approaches and skills. Demonstrate self-guided education pathways for use in training residents.
Telemedicine	One-on-one remote evaluation of white box skills. Personalized direction on improvement and collection of pre-course metrics for improvement.
Group Knowledge	
F2F Discussion	Prior independent activities transform this mode from one-way lecture to two-way discussion. Less focus on basic knowledge and more attention to subtle details and potential solution approaches.
Video Evaluation	Evaluation of video cases as an educated cohort of professionals, rather than one-way explanation of basic features of the case. Highlight situations which will be presented in later group skills sessions.
Team Training	Role playing for basic procedures and extended complications. Table top exercises on resource management and interactions with other departments.
Group Skills	
Simulation VR	Hands-on experience with skills exercises and automated metrics collection, contributing to learning curve improvements. Pre-qualification for use of real instruments and tissue.
Dry Lab	Focus on capabilities and features of instruments, approaches to tissue, planned intervention on patient.
Wet lab	Application of instruments and approach to biological tissue (animal and cadaveric). Focus on response of real tissue to previously learned use of instruments. Environment for some complications and unexpected responses.
OR Observation	Observation of real environment with experienced instructor. Interactive discussion on strategy, expectation, and process. Opportunity for complication and resolution.
Apprenticeship	Partial participation in real environment. Opportunity to perform as part of an experienced team. Open to guidance and criticism by instructor surgeon.

LEARNING METRICS

The technologies that make rich and effective blended learning possible also offer the power of accurate and automated metric collection and computation. Schatz et al (2015) emphasized that blended curricula and systems should create a learner-centric model of education which is data driven and ubiquitously accessible. Technology and blending techniques can transform the industrial model of uniform education into something that is more customized with more objective metrics of performance.

When implementing blended learning programs at IBM, Lewis and Orton (in Bonk and Graham, 2006) reported that evidence of effective programs was determined by (a) student reactions to the experience, (b) measured learning that occurred, (c) evidence of transfer to practice, (d) measurable business impact, and (e) a positive and significant return on investment (ROI).

The metrics of greatest interest in surgical training are almost identical to these. Student reaction to the experience is important for repeatability of the program when surgeons have multiple options for learning the material, as opposed to mandatory programs where the learner cannot select out. Formative and summative assessments are typically part of the educational program to provide feedback to the hospitals or surgical boards that support or prescribe the training. Some of these metrics for a blended program are described in more detail below. Evidence of transfer to practice has been a universally difficult metric to collect. Most courses send surgeons a survey between one and two months post-course asking for their feedback on how the training has impacted their practice of medicine. These are problematic because most surveys are not completed and returned (anecdotal rates are 5-10%), and those that are represent self-reported application without objective data to support the claims. Physician practices and hospital departments do have some ability to measure the business impact of courses which enable new procedures or the use of new devices. These can be measured by the number of patients who have been treated using the new skills and knowledge. Though objectively measurable, this information is typically considered business proprietary and is not shared with the external organizations that provide the training. The medical community would expand the scope of this metric to include "improved patient outcomes" as a measurable business impact which is important to society. Using this same data, practices and hospitals are able to calculate the ROI for new procedures and devices, and this information remains private within the business unit as well. However, business impact and ROI can be inferred when the same organization repeatedly sends surgeons to a program.

Instructional designers are generally most interested in metrics which can be extracted during the educational process as evidence that learning is occurring, as opposed to the other meta-categories given by Lewis and Orton. Some typical metrics which can be collected are shown in Table 3. One purpose and advantage of blended learning is that performance can be improved through multiple learning modalities and learning metrics can extend across multiple modalities to provide a better measure of performance than when confined to a single mode. To illustrate this, the table is structured to show metrics which can be shared in common within a category.

Table 3: Blended Learning Metrics

Independent Knowledge	
Web Course Web Video Web Game	Number of correct/incorrect responses to test questions interspersed within web pages, video, and game vignettes. Efficiency through a game's learning path and selection of correct/incorrect branches in the course, video, or game.
Independent Skills	
White Box Telemedicine	Collection or observation of materials showing incisions, suturing, knots, etc. One-on-one remote evaluation of white box technique.
Group Knowledge	
F2F Discussion Video Evaluation Team Training	Interactive demonstration of knowledge and understanding. Accuracy of role playing and efficiency of resource usage.
Group Skills	
Simulation VR Dry Lab Wet lab OR Observation Apprenticeship	Digital metrics for efficient hand movement, errors, instrument collisions, blood loss, etc. Human observation of same metrics in labs and apprenticeship. Collection of synthetic tissue materials showing incisions, suturing, knots, etc. Damage to biologic and synthetic tissue, blood loss. Discussions with surgeon to demonstrate understanding. Observed and guided technique in apprenticeship.

CONCLUSION

Surgeon leaders like Richard Satava (2009) and Ajit Sachdeva et al (2016) have been promoting the addition of simulation devices to surgical training for a decade or more, along with the integration or blending of this tool with existing modes of training. These efforts have had a noticeable impact on surgical training in specific areas (Gardner et al, 2015). Details on how to implement the integration of simulators have been proposed by various training centers around the country that are associated with the American College of Surgeons.

Most students and instructors have experienced courses in which the age and relevance of the material are in need of revision. Over time content and presentation standards change. Outdated material threatens to provide both incorrect educational materials and an experience that is viewed with disdain because of its visible age. Blending multiple modes and devices into a single learning experience is a challenging endeavor. But, once accomplished, the difficult work is not finished. There remains the challenge of preparing an instructor to lead students through the blended curriculum, installing and training the technical staff that will build and maintain the electronic devices and information resources which enable the course, planning for the sustainability of the program over time in terms of cost and staffing, and planning for technology refresh as the devices and materials age. Kern and Hughes (2009) and McCaffery and Desaulniers (2004) both emphasize the need to keep pace with changes that occur in the teaching and simulation tools and in the knowledge and skills that are being presented. Creating complex blended courses brings with it the added effort and cost of updating the materials across all modes in order to maintain the relevance of the course. Organizations seeking to leverage the immediate advantages of multi-mode blended learning should be aware of the long-term commitment to investing more money and time to keep the material relevant.

Creating a blended surgeon course is not just a project which can be accomplished in the near term and used indefinitely. A course which touches on all of the modes shown in the framework presented here may be effective and impressive for a period of a few years, but will eventually need a substantial investment of time, money, and expertise to maintain its level of educational effectiveness.

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Surgical Simulator Showdown

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ABSTRACT

The introduction of robotic technology in minimally-invasive surgery created a need to develop more efficient and effective training and assessment tools. Virtual reality simulators were introduced to the field to address this need. Currently, there are four da Vinci simulators - the dVSS, dV-Trainer, RoSS, and the RobotiX Mentor. These simulators offer basic training for novice robotic surgeons, familiarizing them with the skills needed to perform safe surgery. While there is literature available for each simulator individually, it can be difficult for a user to select the appropriate system to meet their training needs.

Thus, this paper presents the results of a comparative analysis of the system components of each device (e.g., exercises, scoring metrics, physical dimensions, and student management). Previous research has directly compared three of the four simulators, however this is the first study to compare all four. To collect the information, the team reviewed the device manuals for details on each system, contacted device company representatives, and explored the system capabilities firsthand.

While all systems offer basic skill training in highly immersive 3D environments, each device offers unique advantages and capabilities for training robotic surgeons. The dVSS creates a high-fidelity training environment by leveraging the real robotic surgeon’s console for visualization and control inputs. The dV-Trainer, RoSS, and RobotiX Mentor offer simulated versions of these systems. Each includes system management services for instructors to collect, export, and analyze trainee scores. All systems have been the subject of multiple published validation studies, however these reports do not provide essential details on the nuances of each simulator. The analysis in this paper can be used to aid potential users, buyers, and trainers in identifying the features, which are more essential to their training centers.

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Roger Smith, Ph.D. 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.

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INTRODUCTION

With an increase in the number of minimally-invasive procedures, surgical education has shifted away from the traditional apprenticeship model (i.e., "See one, do one, teach one") towards an experiential framework. Surgical trainees may encounter their first surgical experience on an inanimate training model, excised tissue, or as of more recently, a virtual reality (VR) simulator. These hands-on modalities provide a trainee with the opportunity to become familiar with equipment and instruments, develop skills (e.g., improved dexterity), and increase the understanding of surgical techniques and procedures (Polavarapu, Kulaylat, Sun, & Hamed, 2013).

VR simulation was first introduced to surgical education in the late 1980s (Satava, 1993). Since implementation, VR simulators have been established as valuable training tools for the acquisition of basic surgical skills. They allow a trainee to safely overcome the learning curve associated with new techniques while providing independent and repetitive exposure in a safe and cost-efficient environment (Chou & Handa, 2006). The application of VR simulators in surgery has proven to be essential with the development and implementation of new technology and complex devices.

One such device, Intuitive's da Vinci Robotic Surgical System, introduces unique components not available in traditional surgical techniques. This system provides surgeons with 3D vision, 7 degrees of freedom of laparoscopic instruments, tremor damping, motion amplification, camera stability, and other advanced features (Palep, 2009). In a robotic procedure, the surgeon sits at the surgical console separate from the other surgical team members and patient. From this console the surgeon manipulates master controllers, which translate the surgeon's movements into the smaller, more precise movements of the robotic instruments that are attached to a separate patient cart. The surgeon also controls the camera functionality using these master controllers. The camera provides magnified, stereoscopic vision allowing for depth perception and creation of a synthetic tactile sensation (Figure 1.).

While this system offers multiple benefits, it introduces a technological divide between the surgeon and patient, which can lead to usability factors and a need for a specialized skillset. Providing a trainee with experience on the actual da Vinci system can be difficult due to the associated costs and resources required. Hospitals must make a large capital investment when adopting a robotics program and subsequently must recoup their investment via robotic procedures in the operating room. This often limits access to the system for training to time outside of normal operating room working hours. Along with accessibility limitations, training with the actual system requires the use of Intuitive's surgical instruments, which incur an additional cost.

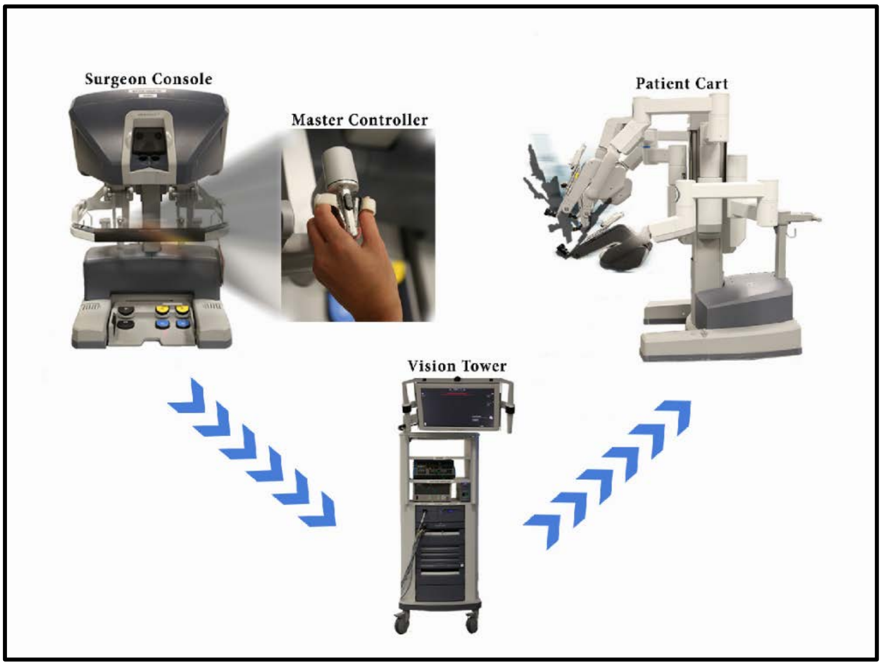

Figure 1. The da Vinci System

Over the last ten years several VR robotic simulators for the da Vinci have become available for educational and training purposes (Figure 2). Currently the commercially available simulation systems are:

- da Vinci Skills Simulator (Intuitive Surgical Inc., Sunnyvale, CA);
- dV-Trainer (Mimic Technologies, Inc., Seattle, WA);
- Robotic Surgical Simulator (Simulated Surgical Skills LLC, Williamsville, NY); and
- RobotiX Mentor (Simbionix USA Inc., Cleveland, OH).

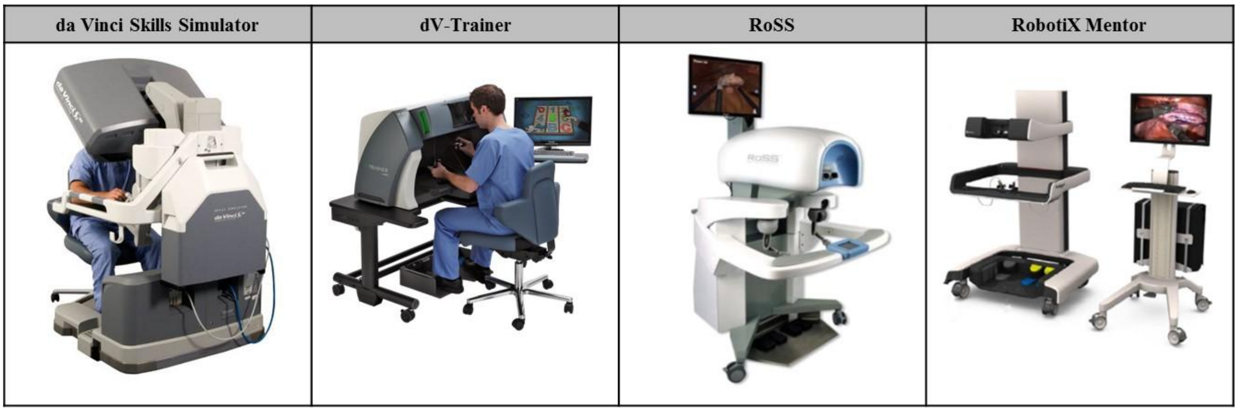

Figure 2. Simulators of the da Vinci Surgical Robot

Most hospitals or training centers will typically invest in only one type of robotic simulator. In general the systems are very similar, however each offers unique capabilities that may make it difficult for an institution to decide on which system is most appropriate for their specific training needs. Thus, there is a need for comparative evaluations of these simulators to aid potential buyers and users in selecting an appropriate device for their purposes.

The objective of this paper is two-fold: to demonstrate a framework for comparing multiple training systems and demonstrate its use by providing readers with an objective comparison of the available VR robotic surgical simulators. This comparative framework provides potential trainers, buyers, users, and instructors with the appropriate information and details needed when considering an investment in an educational training device. This process can be leveraged across various training fields when a comparison of multiple training systems is needed.

This is an extension of a previous analysis, which examined the functionality of only three of the simulators (i.e., da Vinci Skills Simulator, dV-Trainer, and Robotic Surgical Simulator) and illustrated the capabilities side-by-side

(Smith, Truong, & Perez, 2014). Since the previous analysis, new technologies, exercises, and simulators have emerged. This paper provides comparative data on the functionality of the four commercially available robotic simulators.

METHODOLOGY

Before conducting the comparative analysis, the Florida Hospital Nicholson Center research department composed a catalog of the minimum system requirements needed in a robotic simulator to effectively train surgeons. These included hardware and software components, as well as aspects critical for using the system as an education and training tool. These components were identified using expert judgment on the critical aspects of the system that a novice surgeon would need to learn including system components (e.g. controls) and surgical skills that they would need to master (e.g. needle driving). Educational components were also identified to identify what components are necessary for a simulation system that is being used for education. The identified requirements from the actual da Vinci system were used as criteria for each simulation systems (Table 1). These requirements were compared across simulation systems and were used to communicate the accuracy of the simulators features to the actual system (i.e., the realism of the simulators) (Table 2).

Table 1. Selected Criterion for Simulator Comparison

Criterion	Meaning	Purpose
Hardware Components		
Accessibility	Availability of simulator. The system may be a stand-alone system (ability of operating independently of the actual da Vinci surgical system) or embedded (utilizing the da Vinci surgical console).	Provides surgeons with a convenient and easily accessible training device.
Ergonomics	The ability to adjust the stereo viewer, foot pedals, and arm rest.	Provides the surgeon with optimal positioning and maximum comfort.
Master Controllers	Naturally positioned manual manipulators attached to console within a fixed working space.	Used to translate surgeons hand movements into micro-movements of the instruments.
Stereoscopic Visual System	The visual system used in the da Vinci surgical system. This system provides two slightly separate images. When these images are viewed together it creates an impression of depth.	Visual system provides surgeons with a 3D perception to provide surgeons high definition and natural colors.
Software Components		
Exercises	Multiple levels of training scenarios for either basic robotic skills (e.g., suturing skills) or procedural skills for specific robotic procedures.	Provides training scenarios to educate user on proper use of da Vinci surgical system and to provide repeat practice, while providing assessments of user's performance.
Scoring System	Established thresholds that provide users with scoring benchmarks set by expert robotic surgeons.	Benchmarks indicate acceptable and unsatisfactory scoring. Allowing the user or administrator to track progression in each exercise.
User Management	Allows user to create personal accounts. Also, allows administrators or instructors to identify and control the state of users.	Personal accounts allow student account to track and maintain training progress Provides administrators or instructors with the ability to track and manage student accounts.
Curricula Development	Ability for administrators to create and/or assign users a course of study and specified training.	To provide an optimal training based on users experience and training needs.
Data Export	Allows administrators or instructors to pull saved data (e.g., exercise scores, attempts, etc.) for a single student or an entire group.	Exported data can be used to track user's development and progression or can be used for statistical purposes.

From this analysis, the team identified multiple physical components of the actual da Vinci robotic system that must also be present in the simulation systems. That is, each simulation system should mimic major mechanisms of the da Vinci robot including: the master controllers, visual system, foot pedals, ergonomics, and size.

The introductory skills required to use the robotic system are typically offered through basic exercises. These exercises are generally not clinically directed (i.e. require clinical decision making), but are focused on the mechanical and psychomotor skills required to drive the system. The number and types of exercises housed in the simulators were identified. For education and training purposes, it is also essential for the systems to have certain administrative capabilities relevant to the learner and the educator. Specifically, the scoring system, curricula development capabilities, user management functions, and data export process are critical for capturing and communicating learners' performance.

Table 2. Comparison of Simulator Features

Simulator	**Ergonomics**	**Controllers**	**3D vision**	**Foot pedals**	**Admin control**	**Data export**	**Scoring System**	**Basic Robotic Skills Exercises**	**Total Score**
DVSS	+	+	+	+	-	+	+	+	**+7**
dV-Trainer	+	+	+	+	+	+	+	+	**+8**
RoSS	-	+	+	+	+	-	+	+	**+6**
RobotiX Mentor	+	-	+	+	+	+	+	+	**+7**

The team evaluated each system for these requirements by exploring the simulators firsthand, identifying the similarities and unique characteristics across the systems. We elected to purchase all of the systems to ensure that this evaluation remained objective and without undue influence from the manufacturers. The team also reviewed the device manuals to collect additional details about each system (Simbionix RobotiX Mentor User Guide, 2015; Skills Simulator for the da Vinci Si Surgical System, 2013; dV-Trainer Robotic Simulator User's Manual, 2015; Robotic Surgery Simulator User's Manual, 2012). For further information, representatives of each of the manufacturing companies were contacted.

RESULTS

While all systems offer robotic skill training in highly immersive 3D environments, each device offers unique advantages and capabilities for training robotic surgeons. Each of these devices are manufactured by a different company and provides a unique hardware and software solution for training and surgical rehearsal. The sections below describe the different physical and software requirements of the four commercially available da Vinci robotic surgical simulators.

Hardware

Embedded vs Stand-Alone

The majority of the available robotic simulators for the da Vinci system are customized stand-alone systems built to mimic the appearance and technical aspects of the actual da Vinci robot. However, the da Vinci Skills Simulator (dVSS), also referred to as the "Backpack," is a customized computer package that attaches to the actual surgical console through a single fiber optic network cable. Currently, there are two dVSS models, one for each da Vinci Surgical System model available on the market, the da Vinci Si and Si-e surgical system and the da Vinci Xi Surgical System. Each simulator model is only compatible with the corresponding da Vinci Surgical System. In other words, the dVSS Si model is only compatible with the da Vinci Si and Si-e surgical system and the dVSS Xi model is only compatible with the Xi surgical system.

Attached simulators of this type are usually referred to as "embedded trainers" because they leverage equipment that has already been constructed, purchased, and installed for the use of the real system. Embedded trainers are popular in military facilities that may face limited space and weight constraints. These types of trainers significantly reduce the hardware needed solely for training purposes. The U.S. Navy uses embedded simulators aboard ships to reduce weight and space requirements, allowing them to train while the ship is at sea. In addition to saving space, these trainers allow trainees to use the actual controls from the real system to operate the simulator. This type of training provides a realistic experience that is almost identical in feel to the actual system, which may contribute to higher transfer of skills. The dVSS allows the trainee to use the actual surgeon console and corresponding controls that they will use in a surgery, including the master controllers, visual system, and foot pedals.

While embedded trainers offer many advantages, they also come with inherent disadvantages. The entire surgical system can be used for surgery without the simulator however, the simulator relies on access to the surgeon console. Therefore, if the surgeon console is being used in surgery, the simulator cannot be used. The surgical system is expensive and hospitals typically try to maximize the use in the operating room to recoup the investment. In a hospital with a high-volume of robotic surgery program that doesn't have a system dedicated for training, the accessibility and availability of the simulator may be limited.

In addition to availability, embedded trainers increase the amount of use on the actual system. These types of simulators put more usage hours on real controls leading to increased maintenance costs for those devices. That is, heavy use of the dVSS comes with equivalent use of the actual surgeon console, which may ultimately lead to the need for more frequent maintenance. Most maintenance costs are covered by the hospital purchased warranty for the robot, so additional maintenance is typically not a financial cost, but rather impacts the availability of the system for surgical procedures.

The remaining simulators, the dV-Trainer, Robotic Surgical Simulator (RoSS), and Robotix Mentor, are all stand-alone virtual reality simulators that mimic the hardware components of the da Vinci Surgical System. The dV-Trainer, RoSS, and Robotix Mentor are all designed to replicate the appearance of the robotic surgical console including, master controllers, visual system, and foot pedals. Unlike the dVSS, these systems provide training that is independent of the actual da Vinci Surgical System. This provides trainees with a more convenient and easily accessible training device. However, the disadvantage of these systems is that the hardware is simulated and does not exactly replicate the feel of the real robotic controls.

Technical Components

The dV-Trainer consists of three main pieces of equipment: a “Phantom” hood, foot pedals and a desktop computer. The hood replicates the stereo viewer and master controllers of the da Vinci surgeon console. The dV-Trainer foot pedals mimic those on the da Vinci surgeon console footswitch panel. This footswitch panel looks and functions almost identically to the robotic foot pedals. The high-performance desktop computer generates the 3D images and measures the movements of the master controllers. The dV-Trainer also leverages support equipment that includes a touch screen monitor, keyboard, and a mouse that enable an instructor to select exercises to build a curriculum for students and allow an administrator to manage the collected data. This simulator can be configured to imitate the S, Si, and Xi model of the da Vinci robot.

The RoSS is designed as a single piece of hardware with a similar appearance to the robotic surgical console. The hardware device includes a single 3D computer monitor, commercial force feedback devices for hand controls, foot pedals that replicate either the S or the Si model of the da Vinci robot, and an external monitor for the instructor to view. This simulator can be configured to imitate either the S or the Si model of the da Vinci robot.

The Robotix Mentor shares some similarities and differences with the dV-Trainer and RoSS. This system is composed of two mobile carts supporting the hardware equipment. One cart provides the replicated surgeon console with Sony 3D stereoscopic glasses, custom free-floating hand controls, and foot pedals. The surgeon console, controls, and vision system are mimicked in hardware, while a 3D software model replicates the functions of the robotic arms and surgical space. The second cart is connected and contains the high performance graphics computer, monitor, keyboard, and mouse. These components allow instructors to build custom curricula from the available exercises and manage collected data.

Ergonomics

It’s important that training systems provide users with an accurate ergonomic experience as compared to the real system or device. A simulation should not provide an artificially less or more comfortable experience, nor one which is less efficient and responsive than the real system (Smith, 2012). Within these guidelines, user preference and comfort are important considerations for any system. If a user feels as if the simulator is not equivalent to the real system, they may reject its value, become frustrated, and be hesitant to use it. The trainees may also become accustomed to the simulated features and lack knowledge and confidence with the real system. A major benefit to surgeons using the da Vinci surgical system is the improvement in ergonomic characteristics in comparison to traditional surgical techniques (Lux, Marshall, Erturk, & Joseph, 2010). The stereo viewer, foot pedals, and arm rest can be adjusted on the surgeon console, providing the user with maximum comfort and optimal positioning. Thus, it is important for the training systems to mimic the adjustable ergonomic components.

Since it is an embedded trainer, the dVSS allows learners to train in in the exact ergonomic positioning that they would perform surgery. The dV-Trainer provides a custom adjustable table, stereo viewer, and arm rest. While the system's hardware differs from that of the dVSS, it still provides users with the same ergonomic settings.

Only the stereoscopic viewer can be adjusted on the RoSS, which may make it challenging for trainees of differing height to achieve optimal positioning. The RobotiX Mentor allows the trainee to adjust the arm rest, foot pedals, and the stereo viewer, but does not allow the user to change the height of the simulated console.

Master Controllers

The master controllers are the manual manipulators surgeons use to control the instruments and camera. The controllers on the actual da Vinci surgical system are attached to the surgeon console within a fixed working space. On either side of the master controllers are finger clutch buttons. These buttons allow the surgeon to adjust the positioning within the working space to prevent collisions of the master controllers and return the controllers to an ergonomically comfortable position. This functionality can also be accessed via a pedal on the footswitch panel. Each training system should provide a work space similar to the actual da Vinci system, a clutch button capability on both the master controllers and the footswitch panel, and mimic the usability components of the da Vinci's master controls.

All of the simulators provide a mimicked version of the da Vinci Surgical System's hand controls, including a finger clutch component. However, the actual system provides clutch buttons on both sides of the master controllers, an aspect leveraged by the dVSS. However, the standalone trainers (i.e. dV-Trainer, RoSS, and RobotiX Mentor) only provide the clutch button on one side of their controllers. Additionally, the appearance and usability aspects of the master controls differ significantly across all the simulators (Figure 2).

da Vinci Skills Simulator	dV-Trainer	RoSS	RobotiX Mentor

Figure 2. Simulator Hand Controls

The dV-Trainer has unique controls which connect to three cables that measure movement, rather than the more precise master controllers that are used in the da Vinci robot. The RoSS uses modified SensAble Omni Phantom™, force feedback, 3D space controllers (3D Systems Inc., Rock Hill, SC). These devices have a much smaller range of motion than the master controllers on the da Vinci robot and therefore require more frequent clutching than the actual robot. The RobotiX Mentor utilize innovative free-floating hand controls that are tethered to the arm rest by a bundled electronic cable. The attachment and orientation of the hand controls were designed to minimize the interference and weighted drag on hand movements. However, these controllers and mimicked console provide a much larger working space than the da Vinci surgical system, therefore trainees can perform movements in the RobotiX Mentor that cannot be replicated in the actual system.

Such high fidelity instrumentation provides the user with realistic controls in order to raise the level of immersion (Sherman & Craig, 2002). For example, military simulators have demonstrated this in the driving controllers of the Close Combat Tactical Trainer (CCTT) (Johnson, Mastaglio, & Peterson, 1993) and the recoil of simulated rifles in the small arms Engagement Skills Trainer (EST) (Platte & Powers, 2008). For the CCTT armored vehicle trainer, a great deal of effort was put into creating simulated driving controls which accurately mimicked the real vehicle, but which had longer operational life necessary for a training device (Johnson et al., 1993). When developing a surgical simulator the tactile fidelity of the hand controllers is significantly more important and of much higher resolution of control.

Visual system

The visual system in the da Vinci Surgical System provides the surgeons with a true stereoscopic image. The endoscope (i.e the camera inserted into the abdomen) records the visual scene simultaneously with two lenses. The images are transmitted to the user's left and right eye, creating one seamless image in the stereo viewer. Therefore each simulator system was assessed on their ability to mimic a stereoscopic, simulated 3D visual system closest to the real da Vinci surgical system. Each robotic surgical simulators should provide a 3D environment through a mimicked stereo viewer to provide a similar training experience to that of the actual da Vinci robot. As an embedded trainer, the dVSS leverages this hardware to create a high-definition, 3D virtual environment. The dV-Trainer, RoSS and RobotiX Mentor provide simulated technology and hardware to provide a similar experience. The dV-Trainer's visual system uses a similar system to the actual robot: individual images for the left and right eye are transmitted from the computer and into the stereo viewer. The RoSS uses a single 3D computer monitor, built into the system and polarized glasses to produce 3D images, producing a visual scene with less depth of field than the actual da Vinci system. The visual system used in the RobotiX Mentor is also much different than the actual da Vinci surgical console. This viewer uses off-the-shelf Sony 3D stereoscopic glasses. The Sony glasses must be adjusted and focused for each use. To ensure optimal focus and vision, the user must maintain their body position used when originally focusing the viewer. Often, if the user moves the glasses must be readjusted for clear vision.

Vision is often the primary sense used to immerse users into a virtual training experience (Sherman & Craig, 2002). It is imperative to present users with a graphic display that provides visual stimulus and delivers an immersive display, while accurately representing the training material. Slater et al (2009) demonstrated that subjects in a dynamic virtual environment which was created by ray tracing experienced a measurably higher level of immersion and response stress than those who experienced the same environment rendered via the less realistic ray casting method.

Software

Exercise Modules

The exercise modules in each simulator are organized into hierarchical menus according to the surgical skill being addressed and the complexity of the exercise. To ensure effective training there are multiple core skills and relevant tasks that each simulation device should provide within the exercises (Table 3). Each simulator provides on-system instructions for every exercise in the form of textual documents and narrated video demonstrations.

Table 3. Comparative Simulator Exercise Categories

dVSS	dV-Trainer	RoSS	RobotiX Mentor
Surgeon Console Overview Endowrist Manipulation 1 Camera and Clutching Endowrist Manipulation 2 Energy and Dissection Needle Control Needle Driving Games Suturing Skills	Surgeon Console Overview Endowrist Manipulation Camera and Clutching Energy and Dissection Needle Control Needle Driving Troubleshooting Games Suturing Skills	Orientation Module Motor Skills Basic Surgical Skills Intermediate Surgical Skills Hands-on Surgical Training	**Basic Robotic Skills and Tasks:** Robotic Suturing Robotic Single-Site Suturing Stapler Robotic Essential Skills **Procedural Modules:** Hysterectomy Prostatectomy Lobectomy

As described earlier, the dVSS Backpack is available in two different models which match the model of the robot to which it will be connected, either the Si (or Si-e) or the Xi model. There are differences in these two models of the simulator which should be identified. The dVSS Si contains 41 exercises organized into nine categories. Six of the 41 exercises are from the Fundamentals of Robotic Surgery (FRS), a robotic surgical skills education, training, and assessment program for novice robotic surgeons (Smith, Patel, Satava, 2014). These FRS exercises are also available in the dV-Trainer and the RobotiX Mentor. The remaining exercises provide training on many crucial technical skills required for robotic surgery, such as needle control and suturing skills. The Xi introduces 13 new exercises for a total of 47 exercises organized into eight categories. The Xi offers new games and exercises that teach the use of advanced instruments (i.e., stapler) which is a surgical skill not addressed by previous simulators. The other exercises expand on training for camera control, endowrist manipulation and needle driving. Many of the original exercises have improved graphics from recent updates created by Mimic Technologies (Skills Simulator for the da Vinci Xi Surgical System, 2015) and new exercises have been added from a third vendor, SenseGraphics AB (Stockholm,Sweden).

Mimic Technologies and SimbioniX have developed many of the simulation exercises found in both the dVSS Si and Xi. As a result, many of the exercises in the dVSS and the dV-Trainer are similar. However, the current version 3.3 of the dV-Trainer has a number of new exercises, which are not found in the dVSS, and the graphics have been upgraded so the visual presentation is no longer identical. This version of the dV-Trainer contains 65 exercises organized into ten categories. This count includes preview exercises for Maestro AR, described below, and FRS exercises described earlier.

Mimic's Maestro AR (Augmented Reality) provides procedure-specific exercises that allow 3-D interaction between the trainee's virtual robotic instruments and real surgical videos. Maestro AR was designed to train procedure-specific anatomy, procedural steps, and decision-making skills. All of the exercises give instruction and guidance to help trainees identify anatomy and improve their technical skills including grasping, retracting, cutting, and energy application. In addition, the exercises test a trainee's knowledge of the procedural steps with multiple choice questions during the exercise (dV-Trainer Robotic Simulator User's Manual, 2015; Kumar, Smith, & Patel, 2015).

The RoSS simulator contains 52 unique exercises, organized into 5 categories, and arranged from introductory to more advanced. The RoSS system has fewer exercises but most include three levels of difficulty where each level is actually a unique exercise. This company has developed a set of 3-D exercises that are unique from those found in other simulators. They also provide optional video-based surgical exercises, called Hands-on Surgical Training (HoST) modules, in which the user is guided through the movements necessary to complete an actual surgical procedure. These guided videos leverage the force feedback capabilities of the hand controllers to push and pull the student's hands to follow the simulated instruments on the screen. They require the student to perform specific movements accurately during the video before the operation will proceed.

The RobotiX Mentor organizes its' 53 exercises into eight modules which fall under one of two categories: Basic Skills or Procedural Modules. Thirty exercises fall under Basic Skills. Twenty three exercises fall under Procedural Modules which include complete procedures and procedure-specific exercises. Procedural exercises can be performed in a guided or unguided fashion. The guided version of the exercises prompts the user for each step of the surgery or task. In addition, the RobotiX Mentor has exercises that review anatomy and focus on team training. The RobotiX Mentor is the only simulator that offers complete surgeries and procedure-specific exercises in a fully simulated anatomical environment. The RoSS' HoST and the dV-Trainer's Maestro AR do have surgical exercises where the user performs procedure-specific tasks while actual surgical footage plays. However, neither of them offer those tasks in a fully simulated environment. Incorporating such exercises allows students to practice procedures in a safe and reproducible environment, while providing complications and emergent situations.

Scoring System

Upon completion of each exercise, all of the simulators automatically proceed to a scoreboard showing the student's performance on the exercise. All four simulators use the host computer to collect data on the performance of the student in multiple performance areas (i.e. metrics). Using this data, the simulator provides scores for various surgical skills and a total composite score to signifying the user's overall performance on the exercise. In addition to the metrics

collected by the computer, the manufacturers of each simulator have created accompanying thresholds to indicate whether the student is attaining a specified level of proficiency for individual metrics and overall for each exercise. All four systems have identified threshold scores to indicate acceptable and unsatisfactory scoring levels. The thresholds were developed based on the performance of experienced robotic surgeons. These are commonly interpreted as "passing" and "failing" (i.e. above acceptable threshold and below unsatisfactory threshold respectively), with a "warning" area between the two levels. Together these create green, yellow, and red performance areas to visually communicate the quality of the student's performance on each metric

All of the simulator manufacturers worked with experienced robotic surgeons to assist in establishing the relative values of each measure used in the composite score, just as they did for the threshold levels described earlier. Because these evaluations are the opinions of the specific people who collaborated with the company on the development of the system, the dV-Trainer, the RoSS, and the RobotiX Mentor provide the ability for a system administrator to adjust these levels to meet the needs of unique curriculum, courses, and students. However the dVSS is a closed, turnkey system which does not allow for threshold adjustments found in the other simulators.

Each of the four simulators provide a different scoring system. The dVSS uses the Classic System, which represents the trainees score via a percentage of combined pre-established metrics. The dV-Trainer recently shifted from this scoring system and now provides the users score as a composite of total points earned, rather than percentages. This scoring system is known as the Proficiency Scoring System. For this system, the instructor can change proficiency baselines and customize the scoring protocol to fit their needs. The RoSS scoring system follows similar principles of the dVSS and dV-Trainer's scoring systems, however the scoring system is visually communicated differently from the rest. The display presents a horizontal bar, which is colored green, yellow, or red to indicate passing or failing. The magnitude of the bar is a rough measure of the quality of performance (Figure 3). Additional displays show the numeric score and its relative position to a passing threshold.

The RobotiX Mentor scoring metrics vary between simulation modules and cases. Some metrics apply to every exercise while others are only used for exercises in which they are relevant. Due to the novelty of the RobotiX Mentor, proficiency benchmarks have not been set for all exercises yet. Similar to the RoSS' visual representation, exercises with defined proficiency levels provide a horizontal bar colored green, yellow, and red with a marker indicating passing or failing (Figure 3). For benchmarked scores, additional displays showing numeric scores can also be accessed. Exercises without set benchmarks provide a variety of exercise specific metrics divided into categories which are provided in a list format.

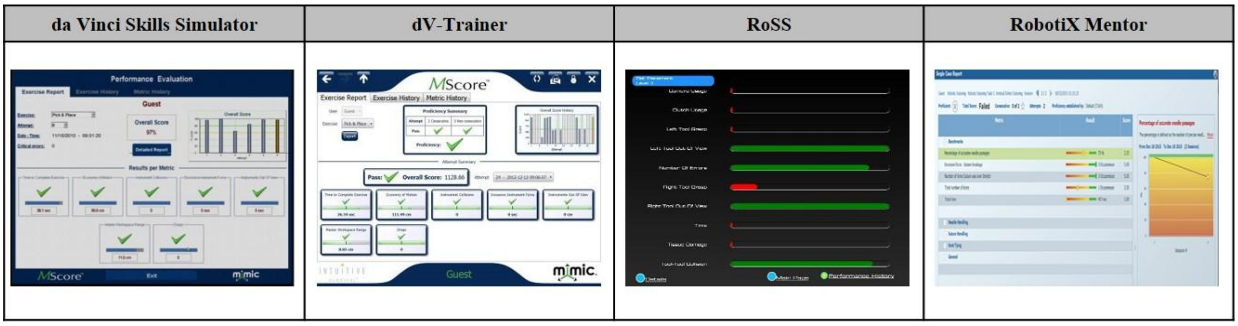

Figure 3. Example Scoreboards from Each Simulator

Progression monitoring and performance measures are two important components that should be incorporated into all educational training systems (Jones, Hennessy, & Deutsh, 1985). Therefore, each scoring systems was compared by their ability to successfully collect key metrics, present thresholds, communicate the learner's performance, and provide progression monitoring. The system should provide meaningful feedback that the trainee can use to specifically target skills that need additional attention and improve future performance. While some scoring systems may translate easily to users, others systems may be less explicit. This may make it difficult for trainees to truly understand areas that need additional training.

User management

Each simulator allows an administrator or instructor to manage and organize student performance according to the unique login credentials of the student. Additionally, all systems have a "guest" account to make the system accessible to anyone, but without the ability to uniquely identify and track individual performance under that guest account. The dV-Trainer, RoSS, and RobotiX Mentor allow the administrator to create user accounts directly from the systems, while the dVSS requires an external PC using a software program provided by Intuitive.

Curricula Development

Once a user account and login credentials have been created, administrators using the dV-Trainer, RoSS, or RobotiX Mentor can create and assign curriculum. The curriculum within the dV-Trainer and Robotix Mentor allow administrators to organize exercises into different assignments or phases. For example, a curriculum may consist of a warm-up phase with easy exercises, pre-course evaluations, and post-course evaluations. These would appear as three separate sections within the curriculum. The exercises in the RoSS simulator are organized into a hierarchical tree structure according to the skills being taught. An administrator for this system can assign a specific branch within this structure as the curriculum for a specific user. But it is not possible to reorganize any set of exercises from multiple branches into a custom curriculum as it is in the dV-Trainer and RobotiX Mentor.

The Robotix Mentor also provides administrators with the ability to add accompanying didactic material (e.g., PDF or video) into a curriculum folder, such as, video of real surgeries that are being simulated. In addition, this simulator includes an administrative management system, MentorLearn, which allows administrators to create, maintain, and assign specific curricula to specific users remotely. The dVSS does not provide administrators the ability to create or assign curriculum to users.

Data Export

All four systems allow administrators to export data as a delimited file directly from the simulators. The dV-Trainer and RobotiX Mentor administrators can export data for a single student or an entire group. Further, these system allow administrators to export data according to multiple criteria, including, all of the data on the machine, or subsets defined by the unique user ID, date range, completion status, or a specific exercise. The dVSS and RoSS administrators can export data files for each student account. While all systems render delimited files that can be removed from these systems for analysis, each system allow administrators to collect student data via different criteria. Some administrators may need to export data through a more sensitive criteria than a student account. The dV-Trainer and RobotiX mentor provide multiple ways to collect student data in comparison to the dVSS and RoSS.

DISCUSSION

Robotic surgery requires a unique set of surgical skills compared to other surgical techniques. Surgical training devices that can provide automated, objective performance assessment is desirable and useful for proficiency-based training. Robotic surgery simulators provide entry-level familiarization and skill development in a safe environment outside of the operating room.

The simulators described in this paper are complex system that are valuable training tools at a lower cost. Each device offers unique capabilities for training robotic surgeons. While each simulator generally provides a physical environment conducive to introducing user to the robotic system, the simulated hardware varies across systems and can be different than the real-world equipment. Learners may experience a trade-off between lower price and perfect accuracy of a simulator. For example, the dVSS allows user to interact with the actual da Vinci surgical console and its features, however this device requires a greater investment than the other stand-alone simulators.

Each system's software components provide trainees with the ability to practice basic robotic skills. Recent advancements in technology has introduced more procedural specific exercises to train an integration of multiple robotic skills and techniques. While all of the simulated devices provide core skills for novice robotic surgeons, more experienced surgeons may benefit most from the RobotiX Mentor’s procedure-specific exercises. In general, each system has some type of learning management system that educators can use to create curricula and track users’ performance. The dV-Trainer, RoSS, and Robotx Mentor provide multiple options for creating, customizing, and building curricula to provide optimal training.

Unfortunately, due to limited accessibility to each of these systems, potential stakeholders may not have the opportunity to experience each of the simulation systems firsthand. However, it is imperative that hospitals critically evaluate the capabilities of training systems and how those capabilities align with their training needs prior to purchasing and incorporating a system into their training curricula. The goal of this analysis is to provide potential users, buyers, instructors, and trainers who have a need for a robotic surgery simulator with the information to make an informed decision on systems that are appropriate for their needs.

It may be difficult for buyers to properly evaluate which system will meet their desired training and educational needs. Yet, if an organization or training center invests in a system that does not meet the learner and instructor needs or does not meet the environmental constraints, the system will not be valuable to the organization, underutilized, and lead to a decrease in return on investment. The process demonstrated in this paper can be leveraged into other domains, when multiple training systems exist in the market.

Prior to purchasing a simulation system, there are several critical components an investor should consider. For an education and training device, it is important to evaluate potential systems for appropriateness to the learning environment. Other factors should also be considered including, whether the system is self-guided or requires management, durability, portability, and the ability to appropriately modify system to meet learning objectives. This process and results of this study will be used to inform future use of the simulation systems at the Nicholson Center.

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Validation for Simulators: It's All About Perspective

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ABSTRACT

Does "validity" refer to the quality of an assessment, reliability of simulator outputs, or accuracy of internal simulation models? This question emerges in medical simulation and training, as educational, clinical, and engineering communities intersect. Each has developed a validation approach to meet their needs, without clear understanding of the other perspectives. Historically, validity has been assessed using a classical framework of content, criterion, and construct validity, concluding that a simulator is or is not valid. Validity has evolved into a unitary concept of construct, consisting of five distinct sources: content, response process, internal structure, relation to other variables, and consequences. Evidence for each source supports a score interpretation for a specific population, under a specific use case. This does not indicate that the assessment itself is generally valid, much less whether the simulator can be relied upon to deliver accurate results.

This unitary framework was adopted by the American Psychological Association as the standard for validating assessments and was recently endorsed as the "gold standard" for validating training tools. While this framework is effective for evaluating the appropriateness of an assessment, it may not be as robust for evaluating a *simulation device* used for assessment. This framework does not account for the physical and functional requirements of a physical system and the implications that discrepancies in those aspects may have on training and assessment.

This paper compares the classical and unitary validity methodologies with a perspective on the application to training simulators, as well as examines the inherent limitations of both. Recommendations and industry standards from other fields are also examined for applicability to surgical simulation. Finally, a recommendation for the validity classification of surgical simulators is proposed. The future of surgical certification and licensing could be reliant on simulation, however validity standards must be established to support this goal.

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Validation for Simulators: It's All About Perspective

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INTRODUCTION

In simulation, many fields converge to create the specialized training tools used to provide learners with standardized environments for the safe acquisition of skills, relying on the expertise of engineers, educators, and subject-matter experts to create valuable training tools. It is imperative that these training systems are vetted to ensure that system performance meets the expected standards, a process typically referred to as validation. The resulting measure of validity refers to the degree to which a model or system is an accurate representation of the real world concept that it is intended to replicate (Sargent 2000, McDougall, 2007, AERA, 1997).

The underlying validation process and associated implications are often subject to the field it is being referenced for. Using a flight simulator as an example, a computer programmer may validate the model in respect to how it performs against an actual system (e.g. aerodynamic characteristics). An engineer may assess whether the controls look and feel representative to the actual aircraft platform, and an educator validates that the flight assessment and After Action Review (AAR) accurately measure and provide relevant feedback on the trainee's performance for a specific testing context.

The surgical field has adopted virtual reality (VR) simulators, similar to flight simulators, as a solution to limited training opportunities, regulated work hours, and a need for advanced training (Kuhn, 1962; Gallagher & Sullivan, 2011). Similar to the validation of a flight simulator, each stakeholder involved in the development and implementation of a surgical simulator has a specific expectation for the concept of validity. The programmers are interested in how closely the physics models of the virtual environment are representative of the real world (e.g. how tissue behaves when retracted) and the engineers verify that the controls function similarly to the actual surgical instruments. The educators and researchers are more concerned with how the benchmarks and scoring system translate to the learners.

The introduction of VR simulators coincided with a drive in the surgical field to move away from the traditional apprenticeship model and towards proficiency-based training. This has been critically important particularly in the specialized field of robotic surgery. Currently, four VR robotic surgery simulators exist. While all of these systems attempt to replicate the controls, visual system, and console of the actual surgical robot, each has unique qualities in regards to software, hardware, and assessment methods (Figure 1). This has resulted in many research studies attempting to validate these systems, as illustrated in a summary of these studies in Smith et al (2015) and Stephanidis (2015).

Figure 1. Different aspects of surgical simulation

The validation studies that have been performed over the last decade have come at a time when medical education and assessment are shifting to new standards. Therefore, the interested educational communities have called for a shift away from the methods of previous studies and towards a new standard process. This discussion has revealed a distinct difference in the perspectives of different communities that are interested in the validation of simulators and of the educational outcomes they provide. In this paper, we present three dominant models for validation which may appear to be in conflict, but which actually represent the distinct needs of different communities, at different phases in a simulator's lifecycle. This paper also provides a process for integrating multiple validation methods for effectively assessing educational technology.

VALIDATION FRAMEWORKS

Multiple professional communities have developed validation frameworks that address their own needs to insure, measure, and certify the accuracy, realism, and assessments provided by a simulator. The work of each of these communities is just beginning to be known to members of the other communities, which is triggering both mild and vehement disagreements about the meaning, purpose, and methods of validation. Cultural and intellectual clashes of these types have occurred repeatedly in other areas of science and engineering. Those cases, as in this, are often fueled by a lack of understanding of the perspectives and needs of the conflicting communities.

In surgical simulation, several frameworks for proving validity have been proposed as the standard for validating educational technology. While the American Psychological Association (APA) endorses a "unitary" framework as the gold standard for validating assessment tools, this model alone does not account for the need to validate simulators from different perspectives in other fields. A shared understanding of all of the perspectives involved may eliminate much of the friction that is being generated in this area. The most prominent validation frameworks from three different communities is shown in Figure 2 and discussed below.

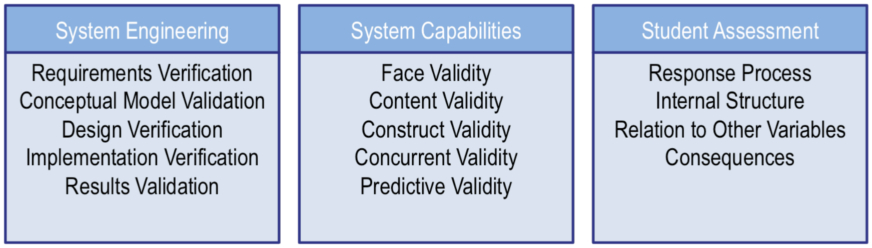

Figure 2. Summary of the validation frameworks

System Engineering Validation

The community that develops simulators and implements a formal process for validating their accuracy and usefulness has relied on Sargent's (2000) model for guidance through the engineering process, and indirectly the work of Balci (1997). In this model, the terms verification, validation, and accreditation (VV&A) are used to increase the preciseness of defining the steps in the process (Figure 3). However, this entire process is appropriately comparable to the other two frameworks that are explored in this paper.

The creators and users of this framework are faced with a different set of problems than those who use of the other validation frameworks. Here, the emphasis is on guiding, controlling, modifying, and using a simulator as a hardware and software system or device. Because simulators are approximate replicas of some real world system, they can be created with dozens or hundreds of different representations of the world which may or may not be accurate and useful models of the real system and the purpose to which they are being put. This process seeks to expose the degree to which the simulator hardware, software, and data effectively represent the real world. This has to be done in the context of the expected application of the simulator. This context is essential in deciding whether compromises which have been made impact or invalidate the usefulness of the simulator in its specific application.

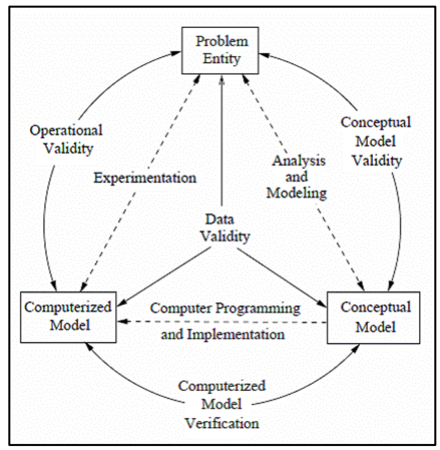

Figure 3. VV&A in Simulator Development (Sargent, 2000)

Sargent's framework has become the de facto validation process in the engineering and development of simulators. It is included in multiple later works which prescribe the process of simulator development and the accompanying validation of the product, such as Tolk (2012), Fishwick (2007), and others. In spite of this prevalence, the Sargent framework does not appear as a reference or an application in any of the medical simulation literature. Those communities come to simulation at a very different time in the system's lifecycle. They more typically encounter a simulator after it has been designed and manufactured for them by a device company. The users of the simulator are then more interested in the degree to which it can assist them with teaching concepts and measuring competence. So their need for validation is entirely at the user experience, educational effectiveness, and student assessment levels. In spite of the fact that the device company may have rigorously applied VV&A ala Sargent (2000) and Tolk (2012), the medical users will insist upon another layer of validation of the product using one of the other frameworks.

Classical Validation

To support the needs of communities using educational devices, to include simulators, the American Educational Research Association (AERA) and the American Psychological Association (APA) proposed a framework for assessing educational tools, typically referred to as the "classical" framework (AERA, 1985). The goal of this validity model is to assess educational tools to ensure that a tool is meeting the educational goals of assessing the specific abilities that it was intended to test.

Under this methodology, evidence is gathered to support a specific inference being made from test scores. For example, if a passing test score implies that a surgeon has the basic skills required to perform the removal of a prostate, then evidence would need to be gathered to support this claim. Under this framework, evidence is grouped into three categories: content related, criterion related, and construct related (Table 1).

Table 1. Summary of the Classical Framework

Validity	Meaning	Example(s)
Construct	A measure indicating the degree to which a test assesses the construct that it is intended on measuring.	What is this test supposed to measure? What is this test actually measuring?
Content	A measure of the degree to which a test's content represents a defined universe or content domain.	What is the content that needs to be tested? Is the test content representative of the actual content? Does the response type and testing format match the universe?
Criterion	A measure of the degree to which the test scores are related to one or more outcome criteria.	Can the test scores accurately predict future performance in the real world? How accurately can the test predict criterion performance?

For *construct related evidence*, information is gathered to support that the test evaluates the specific characteristics of the quality being measured (i.e. does the test evaluate what it is designed to). The construct of interest is often ingrained in the test's conceptual framework and is specific to the construct's meaning, distinguishing it from other constructs and indicating how the measure should relate to other relevant variables. Gathering evidence in this domain may also involve evaluating aspects such as test format or administration, if these circumstances affect the test meaning and interpretation.

Content evidence should demonstrate the degree to which test items, tasks, or questions are representative of a specified universe or area of content, given a proposed use of the test. Gathering evidence in this domain implies determining the content that needs to be tested and determining if the test is representative of that specific content. This also includes evaluating if the testing format and response mechanism is appropriate for the content (e.g. How is a student being assessed for a test on manual skill as opposed to a critical thinking). This type of evidence often relies on expert judgment to assess the relationship between the test and the defined universe, however observation in combination with expert input is acceptable. If a test is going to be used in a way that was not originally intended, the appropriateness of original domain definition needs to be evaluated for the new use.

Criterion evidence demonstrates that test scores are systematically related to one or more relevant outcome criteria. The relationship between test scores and criterion measures may be expressed in several ways, with the goal of determining the accuracy to which the outcome criterion performance can be predicted from scores on the test. In general, there are two designs for obtaining criterion related evidence: concurrent and predictive methods. A predictive study obtains information supporting the accuracy with which test data can be used to estimate future criterion performance. A concurrent study serves the same purpose, but it obtains prediction and criterion information simultaneously.

McDougall (2007) adapted this framework for applicability to medical simulators. Under this modified framework the validation types included face, content, construct, concurrent, and predictive validity. Face validity is typically assessed informally by users and indicates whether the simulator is an accurate representation of the actual system (i.e. the realism of the simulator). Content validity is the measure of the appropriateness of the system as a teaching modality. Experts who are knowledgeable about the device typically assess this via a formal evaluation. Construct validity is the ability of a simulator to measure what it is intended to measure. Often this is characterized by the simulator's ability to differentiate between users' experience level. Concurrent validity is the extent to which the simulator correlates with the "gold standard" for training and predictive validity is the extent to which the simulator can predict a user's future surgical performance. Collectively, concurrent and predictive validity are known as criterion validity and are used as measures of the simulator's ability to correlate trainee performance with their real life performance. Face and content validity are most effective in evaluating the ability of a simulator to train a surgeon; however construct, concurrent, and predictive validity are most useful for evaluating the effectiveness of a simulator to assess a trainee. The majority of literature surrounding the validity of surgical simulators uses these categories defined by McDougall.

Unitary Validation

The AERA and APA updated the classical framework to create a new methodology for validating educational tools, referred to as the "unitary" framework because it views validity as a unitary concept of five sources of evidence: content, response process, internal structure, relations to other variables, and consequences (Table 2). The more evidence collected, the stronger the validity argument is for the test for a specific interpretation, at any given time, for a specific population. Similar to the classic framework proposed by the AERA and APA in 1997, the assessment itself is not considered completely valid or invalid, but is more or less valid.

Table 2. Summary of the Unitary Validation

Validity	Meaning	Example(s)
Test Content	A measure of the degree to which the test's content aligns with the content domain and interpretation of scores.	Are the test items assessing the content and skills that they should?
Response Process	A measure of the degree to which the response mechanisms of the test represent the skills being tested.	Are test takers demonstrating the skills being assessed?
Internal Structure	A measure of the degree to which the format and interrelatedness of the test items aligns with the construct being measured.	Is the test organized as it should be?
Relation to Other Variables	A measure of the degree to which the scores are related to variables outside of the test.	Do the scores align with a test that is currently the gold standard?
Consequences	A measure of the potential consequences of administering the test.	Are the consequences of the test scores relevant to the test's validity?

Test content evidence refers literally to the content of the test being administered. For the purpose of this measure, "content" refers to the test items, to include the wording and formatting of the test, and procedures for administration and scoring. The evidence in this domain includes either a logical or empirical analysis of the adequacy to which the test content represents the content domain and of the relevance of the content domain to the proposed interpretation of test scores. For task-based assessments, as in the case of many simulators, test evaluators create a list of tasks required by the job via observation and advisement of a subject matter expert (SME). The SME judgment assesses the criticality and frequency related to the task performance.

Response process evidence is gathered using a theoretical or empirical analysis of the response processes of test takers, which provides evidence in respect to the appropriateness of the construct and the nature of response mechanism used by the test takers. For example, if a test assesses critical analysis and reasoning, it is important to determine whether examinees are using this skill for the given material. The evidence for this domain is typically generated from an analysis of individual responses, including feedback from test takers regarding their performance strategies or reasoning of responses. In the case of scores being generated by evaluators, evidence can be gathered from the evaluators by determining the extent to which the evaluators are consistent with the interpretation of scores.

Internal structure evidence indicates the degree to which the relationships among the test items comply with the interpretation of the test score. Evidence gathered for this domain would indicate if the items on the test support the assumptions of the interrelatedness of the items. For example if all items on a test will form a comprehensive score, then the test items should be one-dimensional. Test items may imply several aspects of a construct being tested and evidence in this domain determines the extent to which the items' relationships align with the necessity of the test framework.

Evidence gathered in regards to the *relationship to other variables* assesses the relationship of the test score to variables that are external to the test. The external variables can include measures of criteria that the test is expected to predict and relationships to other test scores that are expected to be either convergent or discriminant (i.e.

measuring the same or different constructs respectively). This evidence addresses questions about the degree to which these relationships are consistent with the construct underlying the proposed test interpretation.

Lastly, evidence regarding the *consequences* does not necessarily affect the test's validity, but helps to inform the process of assessing validity. Evidence in this domain determines if there is a consequence of administering the test and if this consequence is relevant to other domains of validity. A finding in this domain of validity is relevant to the validity of the test in general if it can be directly related to another source of validity.

SYMBIOTIC FRAMEWORKS

When applying these frameworks to a simulation system being used for education, we can see that there is not one individually that meets all requirements of a system. While assessment is an essential component of a learning experience, it is not the only aspect that a user relies on for feedback when using a simulation system. Simulators are complex devices that often rely on the replicated controls and interfaces with real-world systems, including user feedback mechanisms (e.g. haptic feedback or visual stimuli). These mechanisms enhance user experience and facilitate learning by providing formative feedback and developing user expectations on how the real-world system should perform. Some simulators, including robotic surgery simulators, provide summative feedback mechanisms to the user at the end of the simulation experience, which helps to reduce the need for a proctor during the trainings (Figure 4). This feedback is often given based on specific criteria and benchmarks that are relevant to the task that the user is performing.

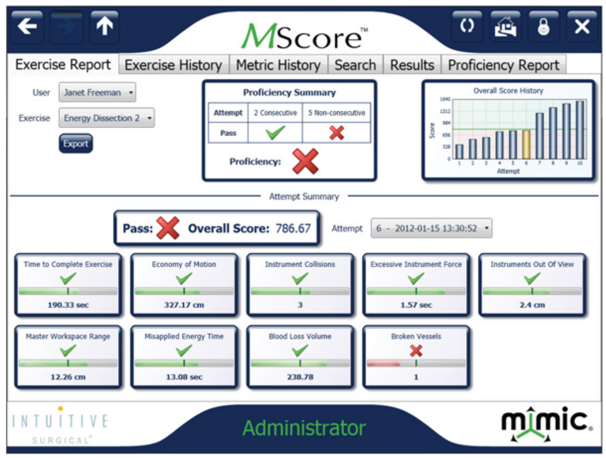

Figure 4. Robotic Surgery simulator summative feedback screen

During the simulation experience, the user makes an input into the system and receives a corresponding output from the system. For example, by moving a camera control towards a target area, the field of view will change to the specified location. By receiving that output the user decides what the next input will be. Using the camera example, if the user over compensates and moves the camera past the target location, they would see this and use the camera control to adjust the field of view. This cycle continues until the simulation experience is complete (Figure 5).

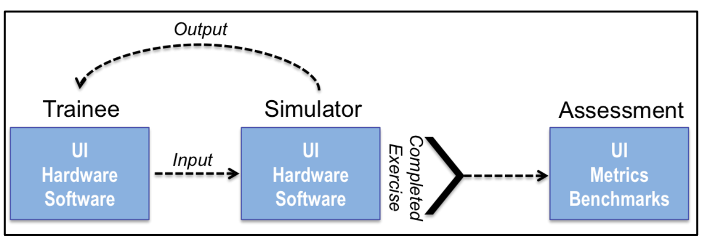

Figure 5. User interaction with simulator

The process of learning via simulation is an experiential process that can be related to the Kolb Experiential Cycle (1984) as shown in Figure 6. When looking at this model, the simulator plays a crucial role in the learning experience of the user. The user expectations are established during the *concrete experience* with the simulator. The learner applies that experience for *reflective observation* and to form an *abstract conceptualization* of how to improve performance. Thus, the user's learning is facilitated through their interactions with the system and the formative feedback that they receive from system.

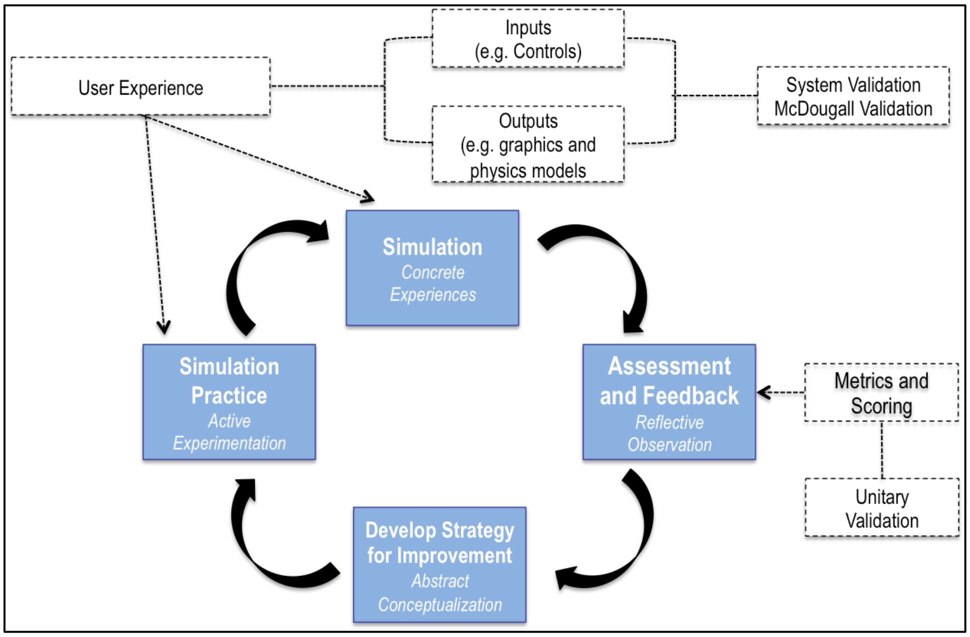

Figure 6. Image showing the relationship of the three frameworks

When looking specifically at the two educational models, the frameworks are designed for evaluating assessments and as such are focused on whether the assessment of the student was an accurate measure of the knowledge and skills that are being evaluated. If we only look at the assessment component of a simulator, then we are only looking at a small portion of the learning experience as a whole. It is possible to have a simulator that meets a high level of educational validity, but is not realistic in terms of engineering design. Conversely, we can have a simulator that almost perfectly replicates the intended system, but does not have meaningful associated metrics. In either case, the user would develop an incorrect model of their knowledge and skills during the training and assessment that would not translate to the real world system.

These frameworks cannot individually address the comprehensive needs for validation of educational simulators and thus need to be used complementarily to one another. Table 3 provides an example of different degrees of validity according to each framework which can be used to evaluate the individual simulator components and to address the needs of educators comprehensively.

Table 3. Validity Levels

	Less Validity	**Moderate Validity**	**More Validity**
Systems Engineering Framework	• Output does not match the real world measures.	• Poor graphics • Pseudo-physics models.	• Highly realistic graphics • Realistic physics models.
Classical Framework (McDougall)	• Replicates real-world system to demonstrate placement of controls, but do not function the same.	• Custom hardware that is more realistic, but not exact.	• Embedded Simulator same hardware as in the real system.
Educational Framework	• Test content does not align with content domain. • Test does not measure what it is intended to.	• The content aligns with the content domain. • The users are not demonstrating the necessary skills	• Test content is relevant to the content domain. • Scores can predict future performance

CONCLUSION

This paper summarizes three prominent and valuable frameworks and demonstrates the role that each takes in the validation process. These frameworks overlap to some degree, no one framework is a complete duplication or replacement of another. Thus, the goal is to explain the rationale for the decidedly different processes that are referred to by the same term and create an awareness of these methodologies, potentially provoking adoption or adaptation. Understanding the value of different frameworks may reduce arguments and contention between communities attempting to apply their own perspective to other communities.

While valuable to specific fields, none of these validation models individually address the comprehensive needs when using simulation technologies as education and training tools. The learning experience when using a simulator encompasses components that should be evaluated distinctly to truly speak to the value of the system as an educational tool. Furthermore, disvaluing one aspect of the system during validation could have detrimental effects on the transfer of training for the user, potentially leading to negative training.

The field of simulation integrates technology, processes, and ideas from several different communities, using technology-rich learning environments to provide learners with a real-world experience for practice and assessment. To say that one method of validation alone is sufficient would be naïve. These frameworks were developed by their respective communities to address that community's specific needs, however needs of the broader simulation community require a more interdisciplinary approach.

It is imperative to critically evaluate not only about what the validation is used for, but also what the validation is evaluating and leverage the qualities of each of the validation frameworks when assessing the validity of a system. We must consider the role that each framework plays in a system and how that affects the learner.

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A Side-by-Side Comparison of Virtual Robotic Surgical Simulators

Florida Hospital Nicholson Center
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Abstract

Background: Since the FDA approved robotically-assisted surgical devices for human surgery in 2000, the number of surgeries utilizing this innovative technology has risen. In 2014, approximately 570,000 robotic-assisted procedures were performed worldwide. Surgeons must be properly trained to safely transition to using such innovative technology. Multiple virtual reality robotic surgical simulators are now commercially available for educational and training purposes. There is a need for comparative evaluations of these simulators to aid users in selecting an appropriate device for their purposes.

Methods: We conducted a comparison of the design and capabilities of all dedicated simulators of the da Vinci robot - the da Vinci Skills Simulator (dVSS) (Intuitive Surgical Inc., Sunnyvale, CA), dV-Trainer (dV-T)(Mimic Technologies Inc., Seattle, WA), Robotic Skills Simulators (RoSS)(Simulated Surgical Skills, LLC, Williamsville, NY), and the RobotiX Mentor (Simbionix USA Inc., Cleveland, OH). This paper provides the base specifications of the hardware and software, with an emphasis on the training capabilities of each system.

Results: Each simulator contains a large number of training exercises, dVSS n=40, dV-T n=65, RoSS n=52, RobotiX Mentor n=31 for skills development. All four offer 3-D visual images but use different display technologies. The dVSS leverages the real robotic surgeon's console to provide visualization, hand controls, and foot pedals. The dV-T RoSS, and RobotiX Mentor created simulated versions of all of these control systems. Each includes systems management services which allow instructors to collect, export, and analyze the scores of students using the simulators.

Conclusions: This study provides comparative information of the four simulators functional capabilities. Each device offers unique advantages and capabilities for training robotic surgeons. Each has been the subject of validation experiments, which have been published in the literature. But those do not provide specific details on the capabilities of the simulators which are necessary for an understanding sufficient to select the one best suited for an organization's needs. This review provides comparative information to assist with that type of selection.

da Vinci Skills Simulator | dV-Trainer | Robotic Skills Simulator | RobotiX Mentor

Background

Since the FDA approved robotically-assisted surgical devices for human surgery in 2000, the number of surgeries utilizing this innovative technology has risen. In 2014, approximately 570,000 robotic-assisted procedures were performed worldwide [1]. Intuitive's da Vinci surgical system is the currently the only FDA approved robotic-assisted surgical device (RASD) for human procedures. This is an innovative surgical technology that allows 3-D vision, 7 degrees of freedom instruments, tremor damping, motion amplification, camera stability, and other features not currently available in traditional minimally-invasive techniques [2]. Investing in a robotic surgery program within a hospital can require significant resources and surgeons must be properly trained to safely adapt any innovative technology. A hospital considering this investment must account for equipment, facilities, personnel, and training. When evaluating the types of training systems to incorporate within the program, it can be difficult to make an informed decision about what system will work best for your hospital. Virtual reality (VR) simulation was first introduced to surgical education in the late 1980s. The first virtual reality robotic simulator was introduced in 2010 [3]. Multiple virtual reality robotic simulators are now commercially available for educational and training purposes.

This is an extension of a previous analysis, which examined the functionality of three of the available simulators (i.e., da Vinci Skills Simulator, dV-Trainer, and Robotic Surgical Simulator) and illustrated the capabilities side-by-side for ease of evaluation by potential users of each device [4]. Since then, new technologies, exercises, and simulators have emerged [5]. The objective of this research is to provide comparative data on the functionality of the four commercially available robotic simulators:

- da Vinci Skills Simulator (Intuitive Surgical Inc., Sunnyvale, CA);
- dV-Trainer (Mimic Technologies, Inc., Seattle, WA)
- Robotic Surgical Simulator (Simulated Surgical Skills LLC, Williamsville, NY):and
- RobotiX Mentor (Simbionix USA Inc., Cleveland, OH).

Methods

The research division of Florida Hospital Nicholson Center purchased the four commercially available VR robotic simulators that are compared in this evaluation. We elected to purchase all of the systems to ensure that this evaluation remained objective and without undue influence from the manufacturers. The team reviewed the device manuals to collect details about each system [5-8]. Representatives of each of the manufacturing companies were also contacted for additional functional details. The authors also explored and compared the capabilities of each device by using each system at the Nicholson Center.

Results

Each simulator utilizes a unique hardware and software for training and surgical rehearsal. All four offer 3-D visual images, but use different display technologies. The general features and capabilities are summarized in Table 1. The differences in hand controls across all the simulators is significant, so images of each of these systems are shown in Figure 1. All of the simulators allow an administrator or instructor to manage and organize student performance according to the unique login credentials of the student, which are provided via unique menu systems (Figure 2). Each simulator contains a large number of training exercises for skills development (dVSS n=40, dV-T n=65, RoSS n=52, RobotiX Mentor n=31). Tables 2-5 show the different exercise categories for the simulators. Each simulator provides on-system instructions for every exercise in the form of textual documents and narrated video demonstrations. All four simulators use the host computer to collect student performance data in multiple performance areas. Using this data, the simulator provides scores for various surgical skills and a overall composite score for the exercise. Examples of each of these scoreboards are shown in Figure 3.

Table 2. dVSS Exercise Categories

Surgeon Console Overview	An introduction to the controls of the da Vinci robot.
Endowrist Manipulation 1	Basic hand movements and usage of the wristed instruments.
Camera and Clutching	Basic foot clutching for both the camera and the third arm.
Endowrist Manipulation 2	Intermediate use of the hands and wristed instruments.
Energy and Dissection	Use of the energy pedals and associated instruments.
Needle Control	Focused exercises for dexterous manipulation of a curved surgical needle.
Needle Driving	Repetitive exercises for needle driving.
Games	Challenging and entertaining game environments to apply the skills learned.
Suturing Skills	Suturing exercises with needle, following suture, knot-tying, and tissue closure.

Table 3. dV-Trainer Exercise Categories

Surgeon Console Overview	An introduction to the controls of the da Vinci robot.
Endowrist Manipulation	Basic and intermediate use of the hand controllers and wristed instruments.
Camera and Clutching	Basic foot clutching for both the camera and the third arm.
Energy and Dissection	Use of the energy pedals and associated instruments.
Needle Control	Focused exercises for dexterous manipulation of a curved surgical needle.
Needle Driving	Repetitive exercises for needle driving.
Troubleshooting	Introduction to error recovery on the da Vinci robot.
Games	Challenging and entertaining game environments to apply the skills learned.
Suturing Skills	Suturing exercises with needle, following suture, knot-tying, and tissue closure.
RTN	VR exercises specifically build to match physical devices in use by the Research Training Network of sites led by Lehigh Valley Hospital.

Table 4. RoSS Exercise Categories

Orientation Module	Introduction to the surgeon controls of the da Vinci robot.
Motor Skills	Development of precise controls of the instruments, including spatial awareness.
Basic Surgical Skills	Instruction on handling a needle, using electrocautery pedals and instruments, and the use of scissors on the robot.
Intermediate Surgical Skills	Control of the fourth arm, blunt tissue dissection, and vessel dissection.
Hands-on Surgical Training	Video and haptic-guided instruction through specific surgical procedures.

Table 5. RobotiX Mentor Exercise Categories

Basic Robotic Skills and Tasks	
Fundamentals of Robotic Surgery **Robotic Suturing** **Robotic Single-Site Suturing** **Stapler** **Robotic Essential Skills**	Instruction on handling a needle, Suturing and knot-tying, basic and intermediate use of the hand controllers and wristed instruments. Control of the fourth arm, blunt tissue dissection, and vessel dissection.
Procedural Modules	
Hysterectomy **Prostatectomy** **Lobectomy**	Specific surgical procedures in a fully simulated anatomical environment (guided or unguided).

Table 1. Robotic Simulator Feature Comparison

Features	DVSS	dV-Trainer	RoSS	RobotiX Mentor
System Manufacturer	Intuitive Surgical Inc.	Mimic Technologies Inc.	Simulated Surgical Systems LLC	Simbionix USA Inc.
Specifications (Simulator only)	Depth 7" Height 25" Width 23" 120 or 240V power	Depth 36" Height 26" Width 44" 120 or 240V power	Depth 44" Height 77" Width 45" 120 or 240V power	Depth 29" Height 55" Width 37" 120 or 240V power
Specifications (Complete System as shown in Figure 1)	Depth 41" Height 65" Width 40" 120 or 240V power	Depth 36" Height 59" Width 54" 120 or 240V power	Depth 44" Height 77" Width 45" 120 or 240V power	Surgeon Tower: Depth 28" Height 56" Width 30" Instructor Tower: Depth 27" Height 59" Width 28" 120 or 240V power
Visual Resolution	VGA 1024 x 768	VGA 1024 x 768	VGA 640 x 480	HD 1280x720
Components	Customized computer attached to da Vinci surgical console	Standard PC, visual system with hand controls, foot pedals.	Single integrated custom simulation device	Surgeon Tower with visual system with hand controls, foot pedals. Instructor Tower to hold support equipment, standard PC,
Support Equipment	da Vinci Si surgical console, custom data cable	Adjustable table, touch screen monitor, keyboard, mouse, protective cover, custom shipping container	USB adapter, keyboard, mouse	Monitor, keyboard, mouse
Exercises	40 simulation exercises	65 simulation exercises	52 simulation exercises.	53 simulation exercises.
Optional Software	PC-based Simulation management	Mshare curriculum sharing web site	Video and Haptics-based Procedure Exercises (HoST)	MentorLearn curriculum management system. Clinical procedures modules with optional team training.
Scoring Method	Scaled 0-100% with passing thresholds in multiple skill areas	Proficiency-based point system with passing thresholds in multiple skill areas	Point system with passing thresholds in multiple skill areas	Proficiency-based point system with passing thresholds in multiple skill areas
Student Data Management	Custom control application for external PC. Export via USB memory stick	Export student data to delimited data file and graphical reports	Export student data to delimited data file	Export student data to delimited data file and graphical reports. Online access to trainee reports
Curriculum Customization	None	Select any combination of exercises. Set passing thresholds and conditions	Select specifically grouped exercises. Set passing thresholds	Select any combination of exercises. Set passing thresholds and conditions
Administrator Functions	Create student accounts on external PC. Import via USB stick	Create student accounts. Customize curriculum	Create student accounts. Customize curriculum	Create student accounts. Customize curriculum
System Setup	None	Calibrate controls	Calibrate controls	Adjust 3D viewer
System Security	Student account ID and password	PC password, Administrator password, Student account ID and password	PC password, Administrator password, Student account ID and password	PC password, Administrator password, Student account ID and password
Simulator Base Price	$85,000	$99,200	$126,000	$95,000
Support Equipment Price	$500,000	$9,800	$0	$0
Total Functional Price	$585,000	$109,000	$126,000	$95,000

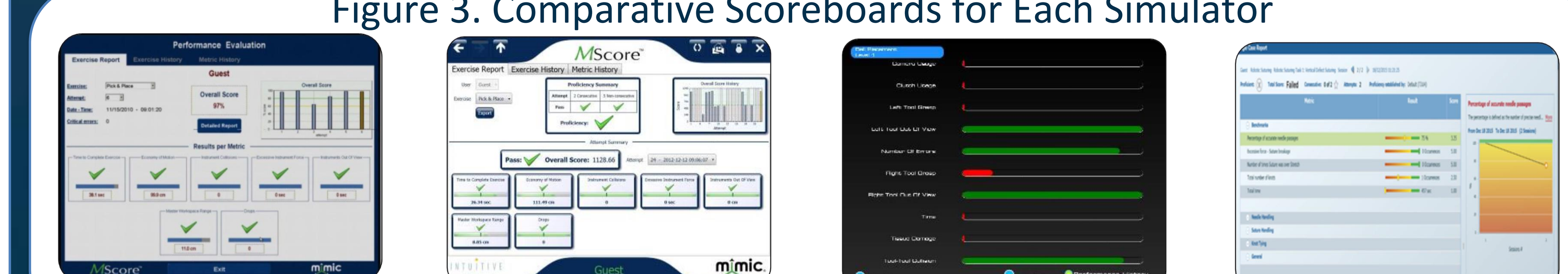
Figure 1. Simulator Master Controllers

da Vinci Skills Simulator | dV-Trainer | RoSS | RobotiX Mentor

Figure 2. Comparative Simulator Exercise Menus

da Vinci Skills Simulator | dV-Trainer | RoSS | RobotiX Mentor

Figure 3. Comparative Scoreboards for Each Simulator



da Vinci Skills Simulator | dV-Trainer | RoSS | RobotiX Mentor

Conclusions

Robotic surgery requires a unique set of surgical skills compared to conventional laparoscopic surgery. A surgical training device that can provide an automated, objective performance assessment is desirable and may be useful for proficiency-based training. Robotic surgery simulators can provide entry-level familiarization and skills development in a safe environment outside of the operating room.

The aim of this research is to provide a comparative analysis of the four commercially available robotic simulators. The simulators described are complex systems, which are significantly less costly to acquire and operate than the actual da Vinci robotic surgical system. This analysis can be used to aid potential users, buyers, instructors, and trainers who have a need for a simulator. Prior publications have directly compared the RoSS, dVSS, and dV-Trainer. This is the first comparison to include the Robotix Mentor.

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Simulator-based Multi-modal Task Decomposition of Robotic Surgical Technique for Vaginal Cuff Closure

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Study Objective: To identify the explicit cognitive and psychomotor steps necessary to complete a robotic vaginal cuff closure, particularly those difficult to master, using a task decomposition. The purpose was to enable exact step replication and outcomes for learners and create an expert model of performance to objectively compare novice performance.

Design: Technique analysis.

Setting: Surgical education and simulation center.

Participants: Expert surgeons, expert simulation educators, expert cognitive psychologists.

Interventions: Expert surgeons performed a vaginal cuff closure on the RobotiX Mentor, a virtual reality (VR) simulator of the da Vinci robot, allowing a repeatable testing environment. The steps were performed deliberately while psychologists recorded details of each action of the surgeon and robotic instruments, as well as deviations that may be considered alternative solutions or erroneous paths. The decisions required to progress the task forward were also captured.

Measurements and Main Results:
The results were constructed into flow charts demonstrating the sequence of actions and decisions surgeons must make. This analysis found three primary steps required to perform the task (Figure 1). The results identified a standard path of 33 actions that experts follow to accomplish the cuff closure. The decomposition found eight actions as reasonable alternatives and 11 relevant decision points required. An example of the decomposition can be seen in Figure 2.

Conclusions: To our knowledge, this is the first multi-modal task analysis for a robotic surgery task, as represented in a VR simulator. These results provide surgical educators with the explicit steps a trainee must master to accurately perform a cuff closure. This process may also be used to create task specific checklists for evaluation by an instructor. These results are the basis for computer algorithms, which will provide a task specific scoring system of the exercise and an intelligent, automated instruction for learners using the simulation.

J Robotic Surg
DOI 10.1007/s11701-015-0540-1

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ORIGINAL ARTICLE

Urology residents experience comparable workload profiles when performing live porcine nephrectomies and robotic surgery virtual reality training modules

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Received: 13 October 2015 / Accepted: 15 October 2015

Abstract In pursuit of improving the quality of residents' education, the Southeastern Section of the American Urological Association (SES AUA) hosts an annual robotic training course for its residents. The workshop involves performing a robotic live porcine nephrectomy as well as virtual reality robotic training modules. The aim of this study was to evaluate workload levels of urology residents when performing a live porcine nephrectomy and the virtual reality robotic surgery training modules employed during this workshop. Twenty-one residents from 14 SES AUA programs participated in 2015. On the first-day residents were taught with didactic lectures by faculty. On the second day, trainees were divided into two groups. Half were asked to perform training modules of the Mimic da Vinci-Trainer (MdVT, Mimic Technologies, Inc., Seattle, WA, USA) for 4 h, while the other half performed nephrectomy procedures on a live porcine model using the da Vinci Si robot (Intuitive Surgical Inc., Sunnyvale, CA, USA). After the first 4 h the groups changed places for another 4-h session. All trainees were asked to complete the NASA-TLX 1-page questionnaire following both the MdVT simulation and live animal model sessions. A significant interface and TLX interaction was observed. The interface by TLX interaction was further analyzed to determine whether the scores of each of the six TLX scales varied across the two interfaces. The means of the TLX scores observed at the two interfaces were similar. The only significant difference was observed for frustration, which was significantly higher at the simulation than the animal model, $t\ (20) = 4.12$, $p = 0.001$. This could be due to trainees' familiarity with live anatomical structures over skill set simulations which remain a real challenge to novice surgeons. Another reason might be that the simulator provides performance metrics for specific performance traits as well as composite scores for entire exercises. Novice trainees experienced substantial mental workload while performing tasks on both the simulator and the live animal model during the robotics course. The NASA-TLX profiles demonstrated that the live animal model and the MdVT were similar in difficulty, as indicated by their comparable workload profiles.

Keywords Robotic surgery training · Mental workload · NASA Task Load Index

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Introduction

Robotic-assisted urologic surgery is predicted to continue to grow in usage in the coming years, and residents trained in urology will increasingly be expected to be proficient in

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MS Code : JORS-D-15-00082 ☑ CP ☑ DISK

robotic surgery [1]. The complexity of robotic technology, its steep learning curve, and work-hour limitation of resident trainees make incorporating robotic training into residency a challenging task. Experts suggest that learning as a bedside assistant for robotic surgery has a rapid plateau; many programs are now utilizing physician assistants and surgical technicians for bedside duties to free the residents for console training [2]. In high volume programs it remains difficult for residents to gain hands-on console time due to their insufficient skill set and the complexity of most procedures.

Robotic simulation training tools can, therefore, be utilized by novice trainees to shorten the learning curve and improve operative skills in a low-risk environment. In pursuit of improving the quality of residents' education, the Southeastern Section of the American Urological Association (SES AUA) hosts an annual robotic training course for its residents. This workshop involves training of basic laparoscopic surgery skills using virtual reality training modules of the Mimic da Vinci-Trainer (MdVT, Mimic Technologies, Inc., Seattle WA, USA) as well as training on performing a nephrectomy using a live porcine model. For simulation training to be successful, it is essential that it (1) practices the relevant skills and (2) matches the level of difficulty (workload demand) similar to the demands experienced in the "real" procedure. Thus, the goal for the present study was to assess whether the workload demands experienced in the virtual simulation training environment, which trains basic robotic surgery skills, match those experienced in when performing the live nephrectomy using a porcine model.

Materials and methods

Select residents from each of the 14 training programs of SES AUA were invited to Orlando, FL, for a 2-day robotics training course. Up to 3 residents were invited from each training program, and 21 participated in the training course. This cohort of residents represented a wider range of training and diversity in experience than in previous courses, being exposed to robotic surgery early at their home institutions. Volunteer faculty were recruited from SES AUA training programs.

The 2015 annual SES AUA robotics training workshop, which is outlined in more detail below, involved training nephrectomy on a porcine model as well as training on the MdVT trainer. Participants' workload we assessed at both interfaces (MdVT and live porcine model) using the NASA Task Load Index (NASA-TLX). The NASA-TLX assesses workload along six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration [3]. Each is measured on a 21-point scale; scores can range between 0 ("Very Low") and 100 ("Very High"), see "Appendix 2".

The SES AUA robotics course is outlined below [4].

Robotic course day 1

A full didactic session was broken into three components. Component 1 covered the basics of robotic surgery including room set-up, bedside assistance, and console essentials. Component 2 covered several aspects of robotic kidney surgery including patient positioning, port placement, and surgical techniques. Component 3 focused on robotic prostate surgery including port placement and different surgical techniques. Didactics were supplemented with surgical videos and discussions of difficult surgical scenarios and possible complications.

Robotic course day 2

The trainees were divided into two groups. Half were asked to perform skill tasks on the Mimic da Vinci-Trainer (MdVT, Mimic Technologies, Inc., Seattle, WA, U.S.A) for 4 h using the dV trainer (version 2) while the other half performed set tasks in a live nephrectomy on porcine model using the da Vinci Si robot (Intuitive Surgical Inc., Sunnyvale, CA). After 4 h the groups changed places for another 4-h session.

Simulation section

In the 4-h MdVT simulation session, trainees were first given a tutorial of the console and its functionality. The trainees then proceeded to complete five exercises with increasing difficulty and required skills. The first exercise, "pick and place", involved simple movements of rings from one pole to another and is used to orient the trainee to the simulator. The second exercise, "peg board" is more advanced and required the trainee to clutch hand instruments while moving the camera, which involves coordinated hand and foot movements. The third exercise, "ring walk", involved moving a ring over a curvy bar without touching the bar with any portion of the ring. This drill requires all the above skills as well as maintaining awareness and accuracy with the ring position at all time. The fourth exercise, "thread the rings", involves passing a curved needle through rings positioned at different angles without touching the ring with any part of the needle. This drill teaches trainees good suturing technique. The last exercise, "tubes 2", is the most challenging and realistic. This drill is designed to replicate performing an urethrovesical anastomosis. It utilizes all of the above skills including accuracy, coordination, and sufficient needle control.

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Animal training section

In the 4-h porcine model live surgery session, all trainees spent 1 h performing cystostomies and cystorrhaphies. They then spent 30 min practicing port insertion and robot docking. Finally, for 2.5 h, trainees conducted a bilateral nephrectomy which included artery, vein, kidney and ureter dissections and ligation.

Questionnaire

All trainees were asked to complete the NASA-TLX 1-page questionnaire following both the MdVT simulation and live animal model sessions.

Results

Twenty-one residents from 14 programs in the SES AUA participated in this course. Seventeen (80.9 %) had used a console during an actual surgical case, while four did not. The distribution of the different levels of training among the residents is shown in Fig. 1. Unlike previous years' courses when only senior or chief residents participated, this course included more junior residents. This reflects a shift toward early exposure to robotic surgery during urology training in most academic programs. The number of robotic surgeries performed or assisted by residents at different levels of training is shown in Fig. 2. Trainees' satisfaction with their program robotic surgery training was assessed (Fig. 3). Of the 17 residents who performed actual robotic surgery, 7 (41.2 %) stated that the simulator replicates real-life robotic surgery, while 10 (58.8 %) stated that it did not.

The NASA-TLX scores were converted to a 0–100 scale with 5-point increments. The raw TLX method was employed to eliminate the weighting process of the different TLX scales. To assess the NASA-TLX data at two interfaces (simulator vs. animal model) for the different levels of training (year of residency), a 4 (training level) × 2 (interface) × 6 (TLX scales) mixed ANOVA was computed. The Greenhouse-Geisser correction was used to correct for violations of the sphericity assumption. The ANOVA indicated a significant main effect for TLX scales, $F\ (3.91, 66.44) = 4.93$, $p = 0.002$, $\eta_{\text{partial}} = 0.225$, as well as a significant interface by TLX scales interaction, $F\ (3.73, 63.42) = 3.73$, $p = 0.016$, $\eta_{\text{partial}} = 0.166$). None of the other main effects and interactions were significant. To further analyze the TLX main effects, Bonferroni-corrected repeated-measures t tests were computed to determine which TLX scales differed significantly from each other; type-I error rate per comparison was set to 0.003. Means of the TLX scales are presented in Fig. 4. As can be seen from Fig. 4, effort resulted in the highest score. The Bonferroni-corrected t-tests indicated that mental demand was significantly higher than physical demand [$t\ (20) = 4.05$, $p = 0.001$] and then frustration

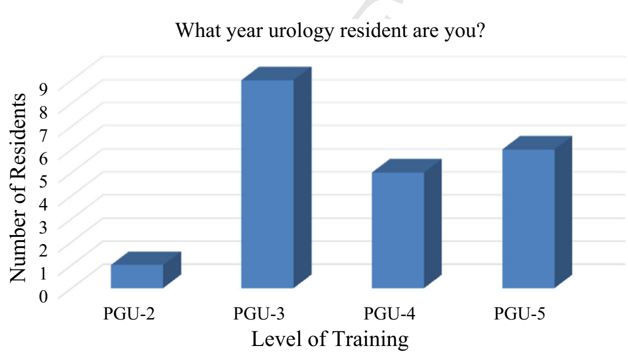

Fig. 1 Robotic Simulator Questionnaire: question 1 results

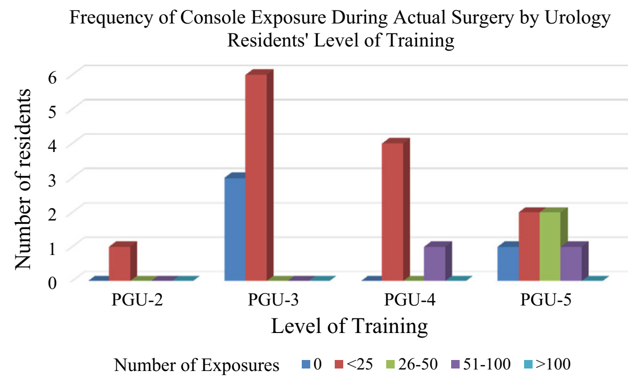

Fig. 2 Robotic Simulator Questionnaire: question 4 results

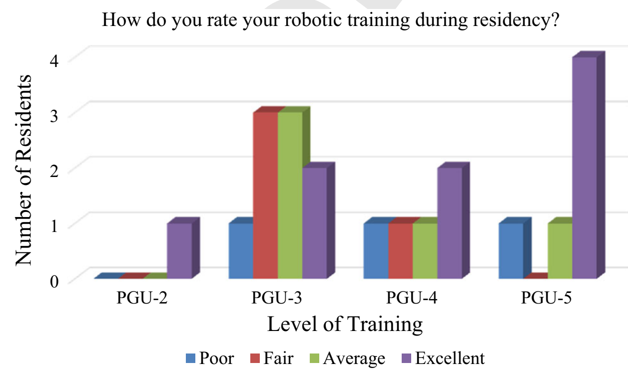

Fig. 3 Robotic Simulator Questionnaire: question 5 results

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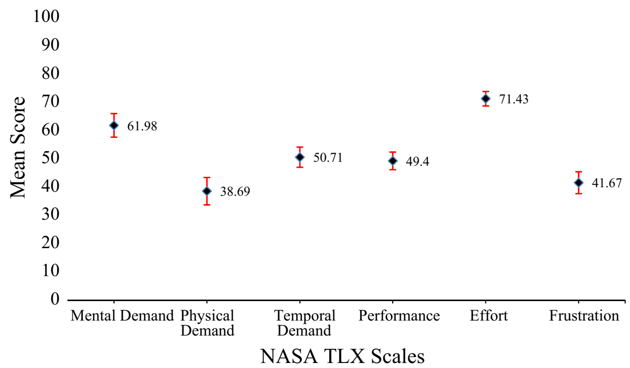

Fig. 4 Mean scores of the NASA-TLX scales. *Error bars* refer to standard error of the mean

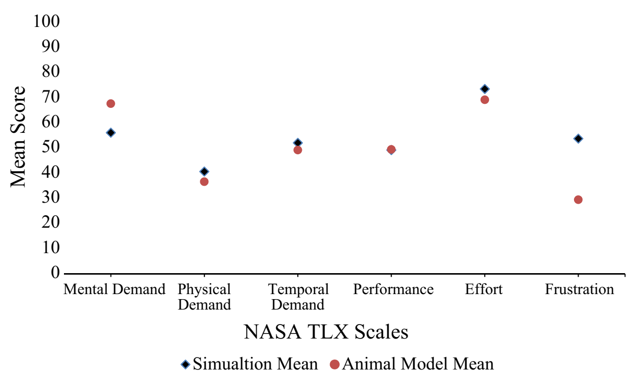

Fig. 5 Mean scores of the NASA-TLX scales in simulation versus animal model

[t (20) = 3.52, $p = 0.002$]. Further, temporal demand was significantly higher than physical demand [t (20) = 2.90, $p = 0.009$] and effort was significantly higher than physical demand [t (20) = 6.52, $p < 0.001$)], temporal demand [t (20) = 5.12, $p < 0.001$], performance [t (20) = 5.15, $p < 0.001$], and frustration [t (20) = 6.90, $p < 0.001$].

The analysis of the interface by TLX interaction was further analyzed to determine whether the scores of each of the six TLX scales varied across the two interfaces. On that end, Bonferroni-corrected repeated-measures t tests were computed; type-I error rate per comparison was set at $\alpha = 0.008$. The means of the TLX scores observed at the two interfaces are in Fig. 5. The only significance was observed for frustration, which was significantly higher at the simulation than the animal model, t (20) = 4.12, $p = 0.001$.

Discussion

Robotic surgery is increasing in popularity in the field of urology due to its minimal invasiveness, reduced risk of complications, and shortened hospital stay. This growing trend is evident in our results. The majority of the trainees this year (80 %) reported live console exposure. In contrast with a similar survey conducted in 2013 in a group of SES AUA trainees, only 56.9 % of the trainees that year reported having had robotic console time [4]. During the 2014 annual training course 92 % of the trainees reported performing live robotic surgery at their home institution [5]. Despite these increasing numbers, there is a lack of standardization and certification process for urology residents in robotic surgery. Furthermore, there is no standardized training protocol for residents learning robotic surgery across the various training programs. Gover et al. suggested a threshold of 25–30 cases for a novice surgeon to begin to operate the foot pedals and controls safely and intuitively [6]. Only 4 (19 %) of our trainees reported having performed more than 25 cases.

Robotic surgery simulators have been proposed to narrow the gap of novice trainees' skill levels [7]. Such simulators can help establish the basics of important operative skills such as eye–hand–foot coordination and using the console controls and foot pedals. Our program chose to use the MdVT simulator for training. The Mimic da Vinci-Trainer (MdVT, Mimic Technologies, Inc., Seattle, WA, and USA) is one of the most established virtual robotic surgical simulators today. Previous research indicated that training on the MdVT resulted in superior surgical performance compared to solely training on the real da Vinci surgical system (Intuitive Surgical Inc., Sunnyvale, CA) when taking a robotic skills assessment using the real da Vinci system [9].

The goal for the present study was to determine whether performance of the robotic surgery simulator tasks employed by the training course of the SES AUA matches the workload demands when performing a real robotic surgery. Towards that end, a porcine nephrectomy was employed. Thus, the results of the present study indicate that the simulation exercises employed by SES AUA generally induce similar workload demands to those experienced when performing a live porcine nephrectomy, indicating that the simulation exercises are not too easy. Specifically, the results indicated that mental demand and effort were major contributors of workload across both surgical interfaces. Further, the different workload dimensions did not significantly differ across the two surgical interfaces, with the exception of frustration. Significantly higher frustration levels were observed at the simulation than the animal. Higher frustration might be due to trainees being more familiar with alive anatomical structures than the simulation exercises. Another potential reason for the simulation to induce higher frustration levels than the animal is that the simulator provides metrics for specific performance traits, as well as a composite performance score [7]. In addition to the objective metrics, the MdVT simulator defines thresholds which indicate whether the trainee's score is considered a "passing" or "failing" performance with acceptable and warning scoring levels, respectively [7]. Conversely, the animal hands-on part did not have objective metric parameters to assess the skill set of trainees in robotic surgery. The faculty of the course subjectively evaluated the proficiency levels of residents when they performed the porcine nephrectomy. Furthermore, the timeframe for every trainee was limited at the robotic console when performing the nephrectomy when compared to the simulation.

However, though training on the MdVT simulator, has been validated [8], its use is not without limitations. There is an initial purchasing cost which ranges from $85,000 to $100,000. These are added costs of annual maintenance fees. There are currently no urology specific procedure modules or simulation drills available but only general surgical skill tasks like the ones used during the SES AUA training course. This limitation could hinder a rapid learning plateau and might not translate to better operative skills without supplementing with real live surgery console time. Therefore, work on more realistic 3D case simulations to advance clinical decision-making and procedural knowledge is currently in progress. The animal lab used for the course in this analysis cost roughly $1,900/h for the animal models, pharmaceuticals, veterinary support, robotic equipment with instruments, PPE, and the specially equipped facility. Other sites have reported $500/h, but this only includes the cost of the animal model, not the entire package of services and equipment [10]. It also lacks realistic human anatomy and might provide a false sense of security which could lead to harming a patient [11]. Future work should be invested in developing urology-specific training modules such as radical prostatectomy and partial nephrectomy simulations. The existing application only hones skills used in general robotic surgery and is not necessarily reflective of skills needed to perform urologic robotic surgery.

Educators and companies have yet to determine the best model to use for teaching robotic surgery. Many factors must be taken into consideration including the cost, availability of expert faculty, legal responsibility on such supervising faculty, risk to patients, and the additional workload on trainees.

These results of the present study, combined with previous and future SES AUA training course results, can significantly enhance our efforts to establish a standardized robotic surgery training program that is cost-effective, practical, and of the highest quality. Encouraging the development of urology-specific robotic training tools in simulation will also aid in reaching our goal. Some limitations of this analysis include its regional focus and limited sample size. It surveyed a limited number of trainees from the SES AUA and is not representative of trainees across the country. The analysis also did not assess the methods each program uses for robotic training. Upon completion of the residency program, many urologists recognize the effort and learing curve involved in acquiring robotic surgery skills and arrive at a consensus that training and proficiency in robotic surgery are necessary during residency [9]. Future direction for this project includes compiling detailed accounts of trainees' exposures at their home institutes. Such analysis combined with future performance scores and trainees' subjective opinions could lead to identifying the most effective methods of training. Work is currently in progress to improve the current robotic training methods.

Conclusions

Trainees experienced similar levels of workload when performing the virtual reality training modules and when performing a live porcine nephrectomy, indicating that the MdVT virtual reality training modules employed by SES AUA workshop have adequate difficulty.

Acknowledgments The authors would like to cordially thank members of Global Robotic Institute Mrs. Ashley Fialkowski and Mrs. Kim Straw for their assistance in obtaining the questionnaires from participants.

Compliance with ethical standards

Conflict of interest Dr Vipul Patel is a consultant for MIMIC Technologies, Inc.

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Appendix 1: Robotic Simulator Questionnaire

1. What year urology resident are you?
   - ☐ Uro-1
   - ☐ Uro-2
   - ☐ Uro-3
   - ☐ Uro-4
   - ☐ Uro-5
2. Does your training program own or have access to a robotics simulator?
   - ☐ No
   - ☐ Mimic Simulator
   - ☐ Ross Simulator
   - ☐ Mimic Backpack or console
   - ☐ Other__________
3. Have you been on the robotics console for an actual case?
   - ☐ Yes
   - ☐ No
4. Approximate the number of cases on which you have robotics console time
   - ☐ <25
   - ☐ 26-50
   - ☐ 51-100
   - ☐ >100
5. How do you rate your robotic training during residency?
   - ☐ Poor
   - ☐ Fair
   - ☐ Average
   - ☐ Excellent
6. In your experience, do you feel that the simulator replicates real life robotics?
   - ☐ Yes
   - ☐ No
7. Which drill did you find the most difficult?
   - ☐ Peg board
   - ☐ Ring Walk
   - ☐ Thread the rings
   - ☐ Tubes 2
8. If your program lacks a robotics simulator, do you think this device would be helpful in your program?
   - ☐ Yes
   - ☐ No

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Appendix 2: NASA TASK Load Index

Name	Task	Date

Mental Demand How mentally demanding was the task?

Very Low — Very High

Physical Demand How physically demanding was the task?

Very Low — Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low — Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

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MS Code : JORS-D-15-00082 | ☑ CP | ☑ DISK

A Side-by-Side Comparison of Virtual Reality Robotic Surgical Simulators

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Patricia Mattingly, M.D., & Roger Smith, Ph.D.

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Introduction

- The number of surgeries utilizing the da Vinci has risen with approximately 650,000 robotic- assisted procedures completed worldwide in 2015.
- Investing in a robotic surgery program can require significant resources.

Introduction

- Evaluating types of training systems to incorporate into program can be difficult.
- Multiple virtual reality robotic simulators are now available for educational and training purposes.
- **Objective:** Provide comparative data on the capabilities and functionality of the four commercially available robotic simulators.

Materials & Methods

Simulators Compared

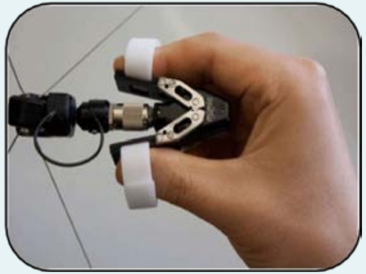
da Vinci Skills Simulator

dV-Trainer

Robotic Skills Simulator

RobotiX Mentor

RESULTS: Features & Capabilities

dVSS	dV-Trainer	RoSS	RobotiX Mentor
Base Price: $85,000 Support Equipment: $500,000 **Total:** $585,000	Base Price: $99,200 Support Equipment: $9,800 **Total:** $109,000	Base Price: $126,000 Support Equipment: $0 **Total:** $126,000	Base Price: $95,000 Support Equipment: $0 **Total:** $95,000
			
			

Results

Exercise Modules

Results

Scoring Systems

Results

System Administration

- Simulators contain system configuration and student management functions.
- Record and export student scores for evaluation and analysis.
- dVSS administrator functions are fixed within the system and cannot be changed.
- dV-Trainer, RoSS, & RobotiX Mentor: create new users, curricula, and set passing thresholds.

In Summary

- Robotic surgery simulators can provide entry-level familiarization and skills development in a safe environment outside of the operating room.
- The simulators described in this study are complex training systems that are less costly to than the actual da Vinci system.

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In Summary

- This is the first analysis to directly compare all four simulators.
- This analysis can be used to aid potential users, buyers, instructors, and trainers who have a need for a simulator.
- Which system is right for you?

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THANK YOU, QUESTIONS?

Response to "Unlike History, Should a Simulator Not Repeat Itself?" *Simulation in Healthcare* 2015; 10(6): 331-335

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Response to "Unlike History, Should a Simulator Not Repeat Itself?" *Simulation in Healthcare* 2015; 10(6): 331-335

To the Editor,

I have read with great interest Dr. Lampotang's editorial in the December 2015 issue of Simulation in Healthcare [1]. The author has provided an excellent overview of some of the benefits of and the difficulty in achieving repeatability in healthcare training simulations. The categories and examples included should become common references for our unique niche of the simulation community in the years to come. The topic of repeatability has also been actively investigated in interactive, networked, and parallel simulation systems, often associated with military training applications. That community has literally created hundreds of simulation systems to address various problems and found repeatability to be important in applications like analytic wargames which needs to be run hundreds of times with very controlled differences in actions, but without uncontrolled variations from internal algorithms or data transfer times. Distributed simulation events which link multiple simulators via computer networks also encounter undesired repeatability issues primarily from two causes, differences in message delivery times from one run to another and the internal logic used to sequence events received from external systems which all have the same logical simulation time. These simulation communities have developed algorithms which specifically control for these variations and software infrastructures which attempt to provide these capabilities as a service to any simulator that uses them. [2,3]

The definition that the author provides for repeatability is concise and useful from the perspective of the human users of the simulation. *"Repeatability is the measure of the similarity in the outputs of a simulator during repeated runs of a given scenario with identical inputs, interventions, and events at the exact same times."* This correctly identifies the fact that identical output relies upon identical input in all of its forms. A simulation system of any significant complexity is prone to a large number of uncontrolled input factors and internal operations which make repeatability extremely difficult to achieve. This response will present some of the most common of these.

When a simulation is a closed, single computer system that is driven only by preloaded digital data files, achieving repeatability is relatively straight forward. These systems can be said to be deterministic and can be structured to provide perfect repeatability, just as a calculator provides perfectly repeatable answers to the same problem every time. But when a simulation is part of an interactive, real-time experience that includes input from external systems like human participants and other computer devices, repeatability is much more difficult to insure, and may be impossible.

For complex systems like these, repeatability can be explored at multiple levels. Lampotang explicitly identifies the model, simulator, and simulated environment [1]. He also provides examples of the information delivery between two devices, but does not list it with the other three. He has given several excellent examples where the linking of multiple devices and the interfaces between them can create uncontrolled variation which leads to non-repeatable outcomes. These various sources might more clearly be identified as stemming from *external systems* such as the humans, computers, and devices that are part of the simulated environment; *information delivery* which includes computer networks or physical delivery lines that carry data or physical triggers to a simulator; *internal interpretation* by logic within the simulator that is used for managing and scheduling events that are internally generated or received from external systems; and *internal models* that use algorithms which may or may not provide repeatable results. Describing these sources or variation has been attempted in previous publications, though without the explicit terminology provided here [2,3,4]. Examples of how each of these can impact repeatability are provided below.

When seeking repeatability, it is necessary to understand the basis of the internal models or algorithms which perform the computations within the simulator. In many fields, the lack of perfect knowledge of the domain (e.g. the human body) has led to the use of stochastic and statistical models to represent the richness and diversity of the domain. These models usually rely on a random number generator (RNG) as a source of input data. As the author points out, various races respond differently to anesthesia, as do different sexes, and body masses. The details needed to model this deterministically are often unavailable or too complex to include in a simulator. In these cases, simplified tables of average responses and standard deviations around those averages are often used along with stochastic and statistical algorithms which create variability within these defined limits [5]. Together these create a simulator in which a 40 year-old, Caucasian male, 6’0”, with a BMI of 25 does not always respond exactly the same to a volume of anesthetic, but always responds within known ranges for a person of that type. Such variability may be desirable for realism and uniqueness of training events, but is undesirable when repeatability is a goal.

RNGs come in many forms, some provided as software libraries and others cleverly contrived by software programmers. In all cases, these actually generate pseudo-random numbers with a demonstrable level of bias or skew. Avoiding all use of RNGs and algorithms that depend on them is one step toward creating a repeatable simulation at the model level. RNGs found in software libraries often make use of a "seed number" which kicks off a long sequence of random numbers throughout the execution of the simulation. In these cases, deliberately using the same seed number at the beginning of every simulation event will lead to the same sequence of pseudo-random numbers throughout the event. However, this apparent repeatability can be thwarted by human actions and by system behaviors during a run, as will be explained.

Inputs from an external system can also result in different computational outcomes. These systems may be both human users and external, networked computer devices. In both cases, the events which are generated externally and become inputs to a simulation can contain varying content which will throw off the repeatability of the simulator. These variations are much more common and extreme when the external system is a human trainee or instructor, but also occur when they originate from another simulator or device. When the events contain different contents due to slightly different actions taken externally, this information can easily lead to different decisions in the receiving simulation, change its internal state variables, and pass that variation on to the human trainee in its output. For example, when an injection of adrenalin is required to stimulate the heart, if the injection is provided only one minute later from one trial to the next, the simulator may cross an internally programmed threshold in the software. When the adrenalin is applied before this threshold is reached the patient may live, when applied afterward the patient may die, even when the difference in the two times is only a few seconds. Such an extreme boundary may not be typical of most real life situations, but it is very common for software algorithms and data tables which are programmed into all types of simulations, creating these types of hard thresholds.

Variation can also be triggered when external events are received with exactly the same internal content, but arriving at a different time or in a different order. When this occurs the simulator may receive and process event B before event A (B < A), rather than A < B as in a previous run. This reversal of order can be caused for multiple reasons; most commonly because the events were actually generated at a different time by a human user, but also when a different computer system is not strictly synchronized and can send events at different times during a second or third run of the simulation scenario. Also, when two or more simulators are linked together electronically, if one simulator generates multiple events at the same simulated time, these events may be delivered to another simulator in the same order, but because they have the same time stamp on them, they can logically and correctly be processed in either sequence A < B or B < A, which contributes to non-repeatability. If a controlled RNG is being used as described above, even the use of the same seed number on multiple runs cannot prevent this reversal of event order from reversing the application of the RNGs which were used on a previous run. There are several advanced parallel and distributed simulation infrastructures which can be used to insure that multiple simulators are synchronized and events are always processed in the same order [3,6]. These include infrastructure software like SPEEDES which was developed by the NASA Jet Propulsion Laboratories and is available as a product from WarpIV Technologies; and the High Level Architecture (HLA) Runtime Infrastructure (RTI) which was designed by the US Department of Defense and is available as a product from multiple companies (e.g. VT MAK Inc., Pitch Technologies Inc.) These can eliminate variation within computer simulators, but they cannot correct or control the variation caused by human input.

Medical simulation often looks to the military as a front runner in simulation techniques and technologies. Flight simulators, which were cited by the author and are widely understood by the public, are actually some of the most rudimentary and straightforward of these systems. As the author points out, these simulate the behavior of machines which has been engineered by humans and are much better understood than the human body. But, there are many military simulators that include models human behavior (e.g. OneSAF and SOAR), acting as individuals and groups; all of which wrestle with complexities similar to that found in modeling human physiology. Attempts to represent these behaviors have led directly to the creation of new fields of study or have expanded on existing fields – such as stochastic modeling, agent-based modeling, artificial intelligence, and machine learning. Some of these techniques may be useful in modeling human physiology and its response to various external medical and trauma stimuli.

In summary, when humans and other sources of external stimuli are part of a simulation driven event, there are almost always sources of variation which can and will lead to non-repeatable runs of the scenario. Controlling as much of the externally generated stimuli as possible is the best option for approaching repeatability. It can lead to scenarios which are indistinguishable from each other most of the time, even though their internal state variables may have many differences. But, on occasion, these differences will cross important thresholds which will lead to very different outcomes. True repeatability requires a level of control of the internal models, internal interpretation, information delivery, and external systems which is very difficult and costly to achieve. Recognizing when unexpected variation has changed the outcome of either training or assessment using a simulator is the responsibility of experienced human proctors and trainers. Simulated environments remain an approximation of the real world, but they also contain a level of complexity which makes them as difficult to control as it is to control the real world.

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Improving the Cognitive Leaning Ergonomics of Surgeons

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Abstract

For centuries, the cognitive ergonomics of all learning environments have been driven by the availability of resources for training and education, rather than aligned with the best methods of transferring knowledge and skills from an expert to a novice. This Industrial Age education has become ingrained in all major education systems and is the basis from which most curricula are built. Medical education has followed suit for centuries, using apprenticeships and experiential learning on actual patients for skill acquisition. In these technologically sparse educational environments, the repercussions from an error were considered unfortunate for the patient, but accepted as a good for society as a whole.

However, 21st century technologies provide alternatives for training medical providers, which shift the risks from human patients to computer and media-based tools that are much more resilient to mistakes made during the learning process. These tools not only allow hands-on practice in a safe environment, but also provide the repeated practice necessary to refine skills. With the introduction of such technologies and related objective skill assessments, the field has also seen a push for proficiency-based evaluation of skill for practitioners.

The impact of technology driven educational devices on education and training is just beginning. These tools appear to offer higher levels of learning and skill acquisition with fewer negative impacts on patient safety, practitioner's learning, and accreditation. In this session we will describe the advantages to practitioners, patients, and accreditation authorities of making more aggressive use of computer-based simulators in the education process.

Learning Environment & Equipment

Teaching a Unique Audience

Practicing
Surgeon
Age 32-40

- Attending – 2-10 Years
- Fellowship – 2 Years
- Residency – 4-5 Years
- MD – 4 Years
- BS – 4 Years
- High School – Cum Laude

How does this person learn best?

Traditional Learning Matrix

	Independent	Group
Knowledge	<u>Web-Based</u> Introduction Preparatory Cognitive	<u>Lecture</u> Deep Knowledge One-way Surgical Video
Skills	<u>None</u>	<u>Hands On</u> Laboratory Bio/Syn Tissue Surgical Video

Fundamentals of Robotic Surgery

Online Curriculum

Live Courses

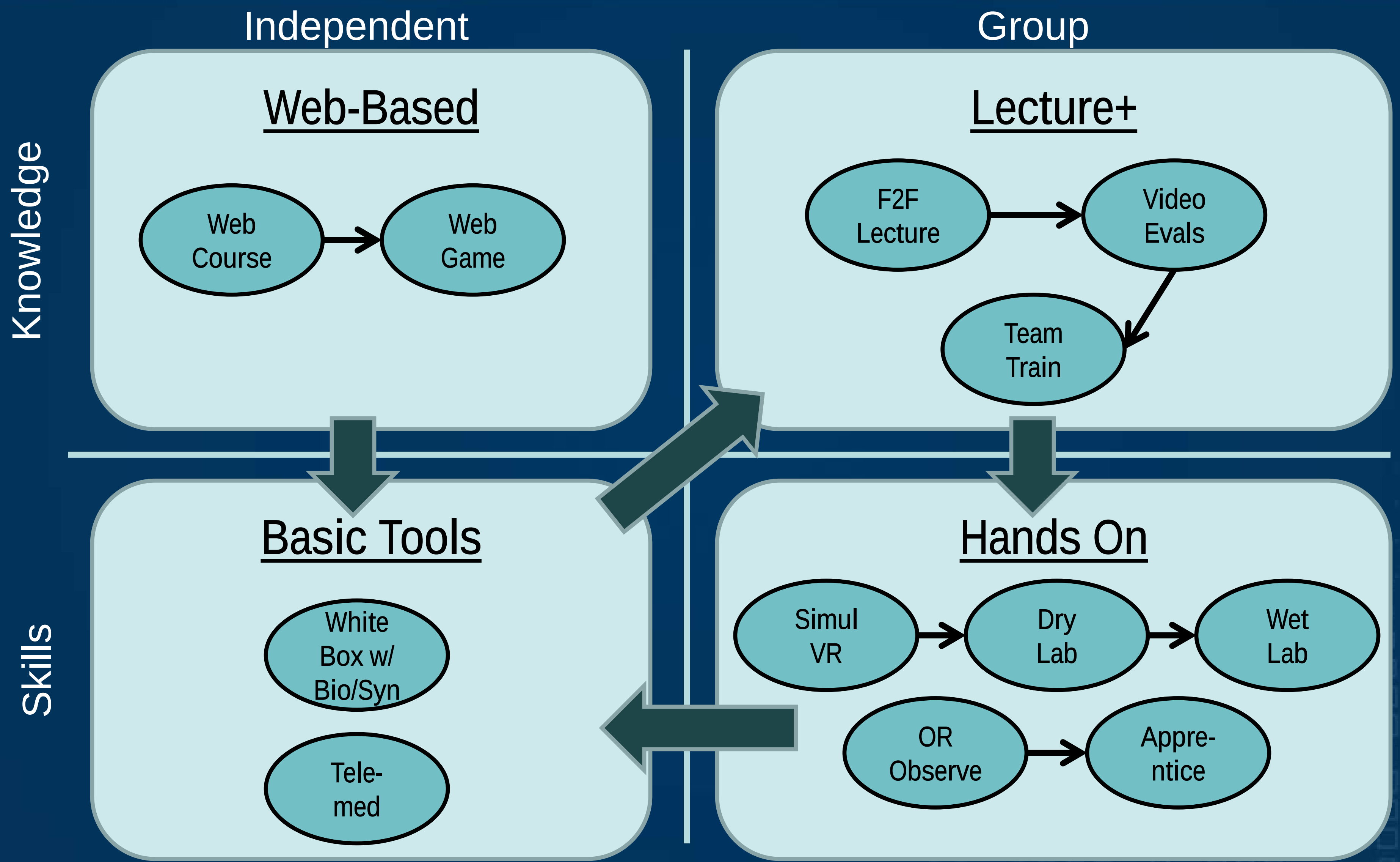
Team Training

Psychomotor Skills Devices

Surgical Education Tools/Modes

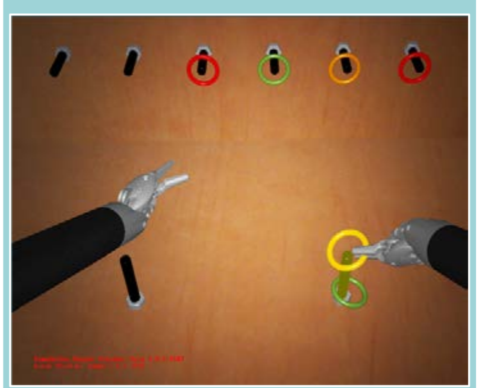
White Box	Sim VR	Dry Lab	Wet Lab	Web Game	Team RoleP	Tele Med	OR Observ

Cognitive Ergonomics Learning Matrix

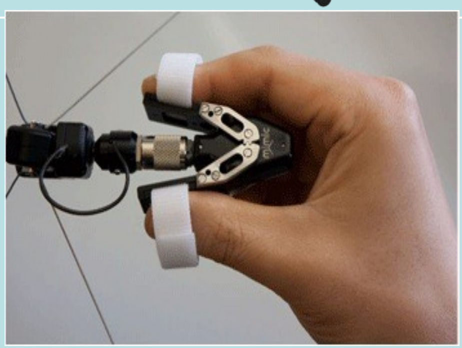


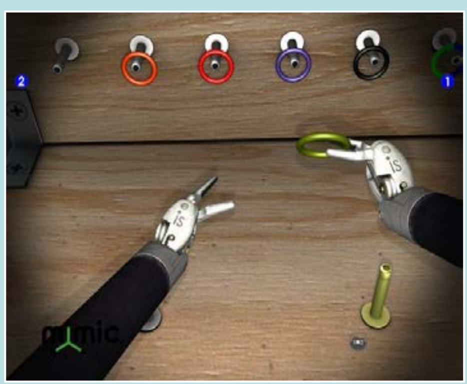
Robotic Surgery Simulators

Intuitive DVSS

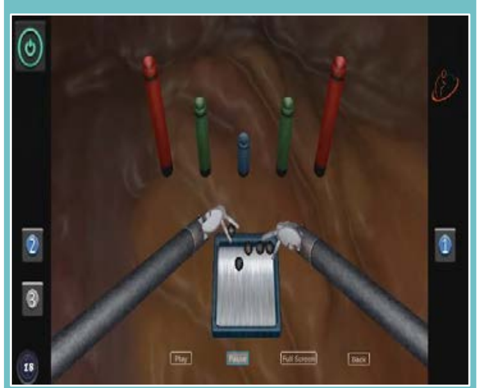


Mimic dV-Trainer

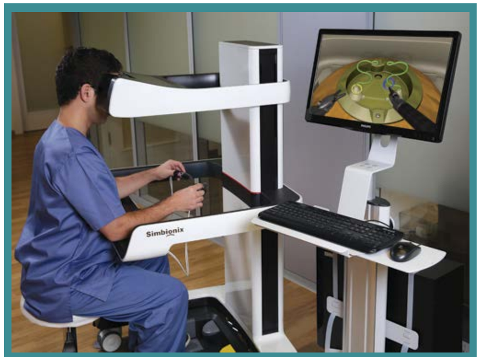


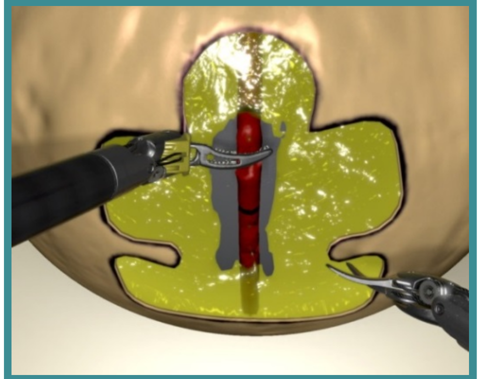


Sim Surg RoSS



Simbionix Robotix Mentor





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Robots in Surgery & Simulation in Training

Roger Smith, PhD

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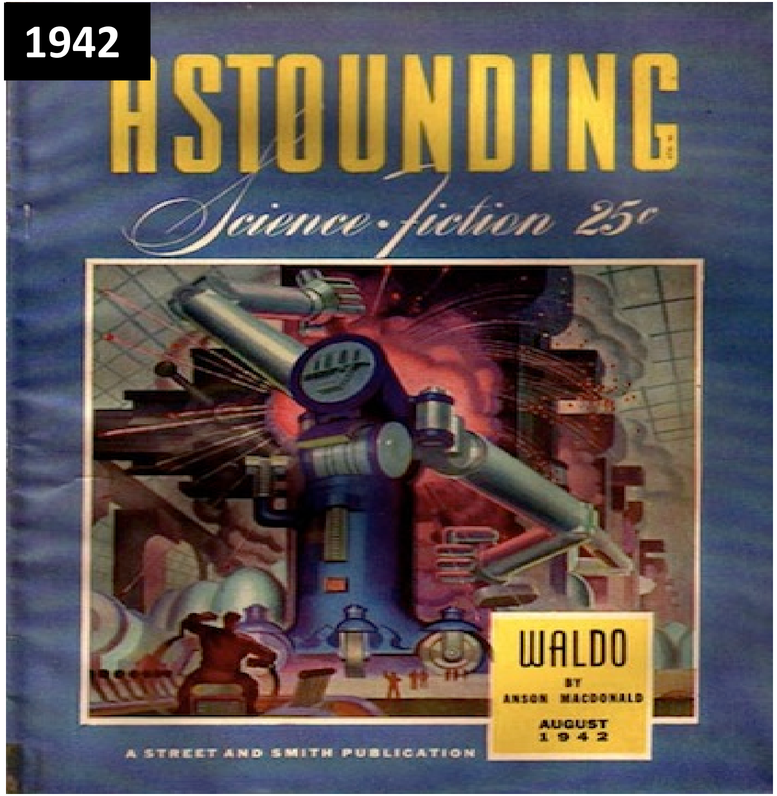
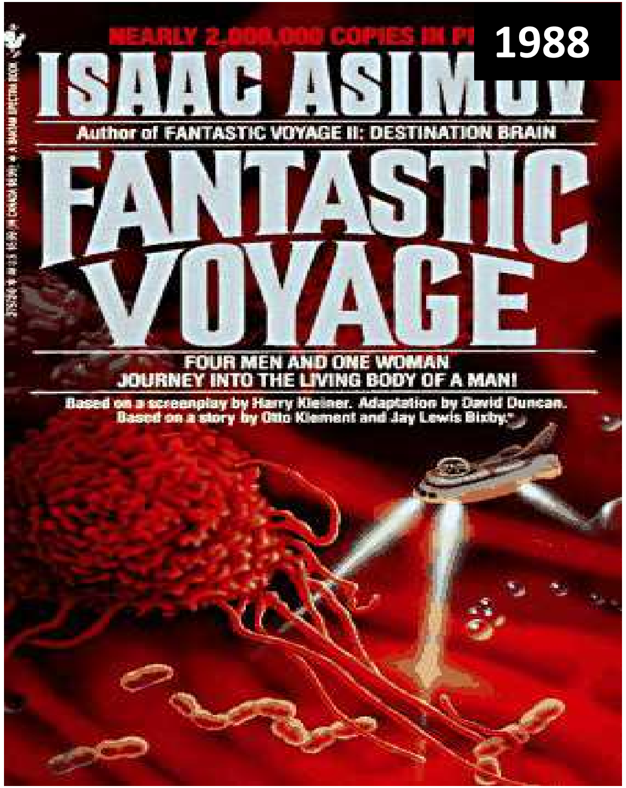
IEEE

Robotic Surgery in Science Fiction

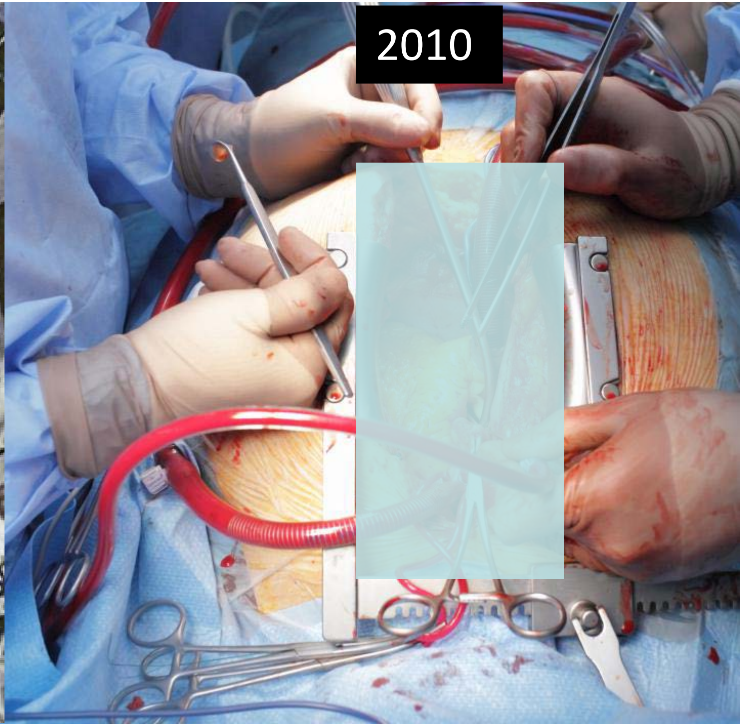
1942



1988

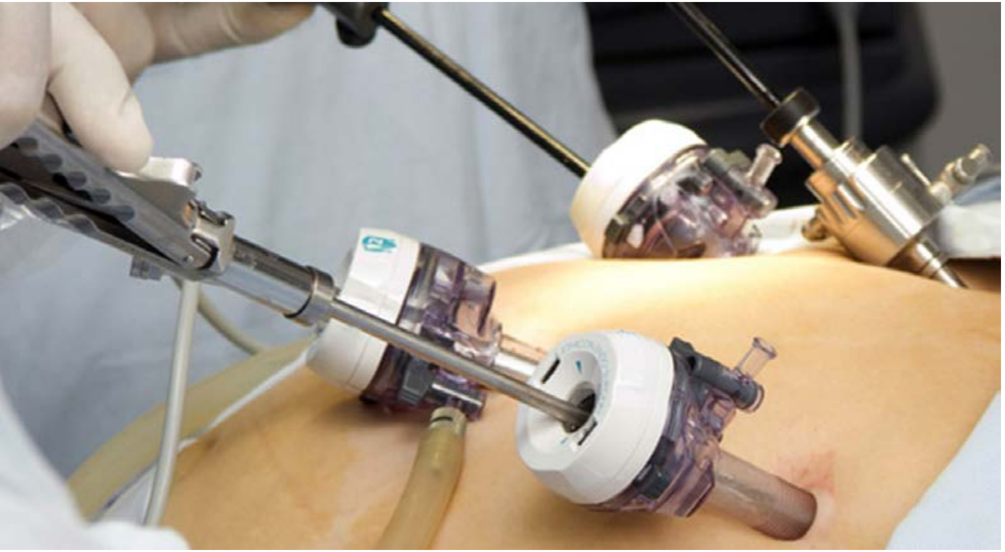


Open Surgery

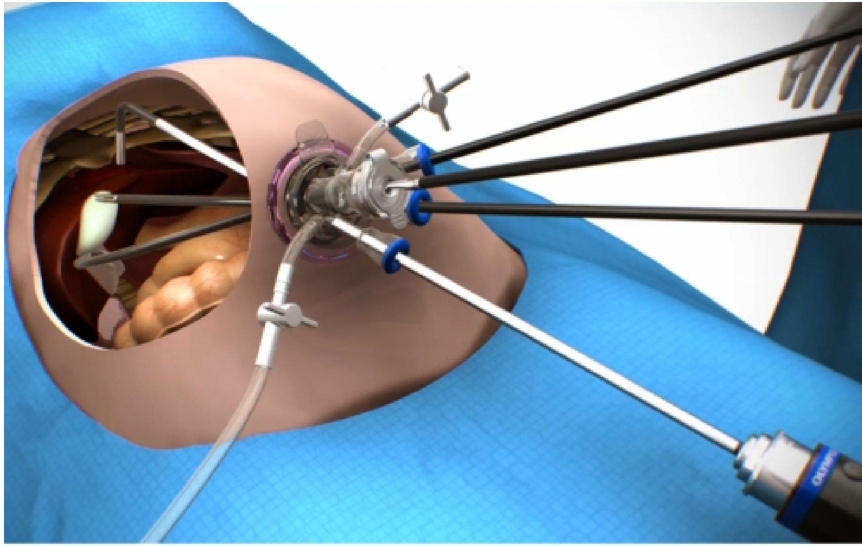


Minimally Invasive Surgery

1980's Laparoscopy



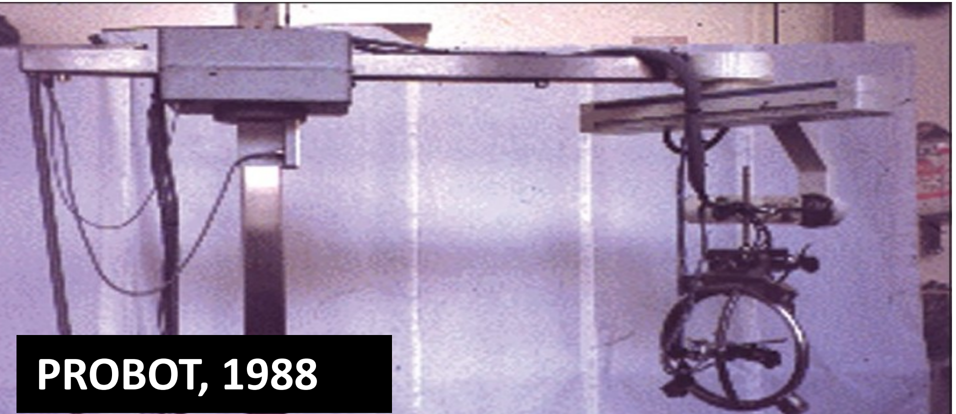
2000's Single Port



Seeking Robotic Augmentation

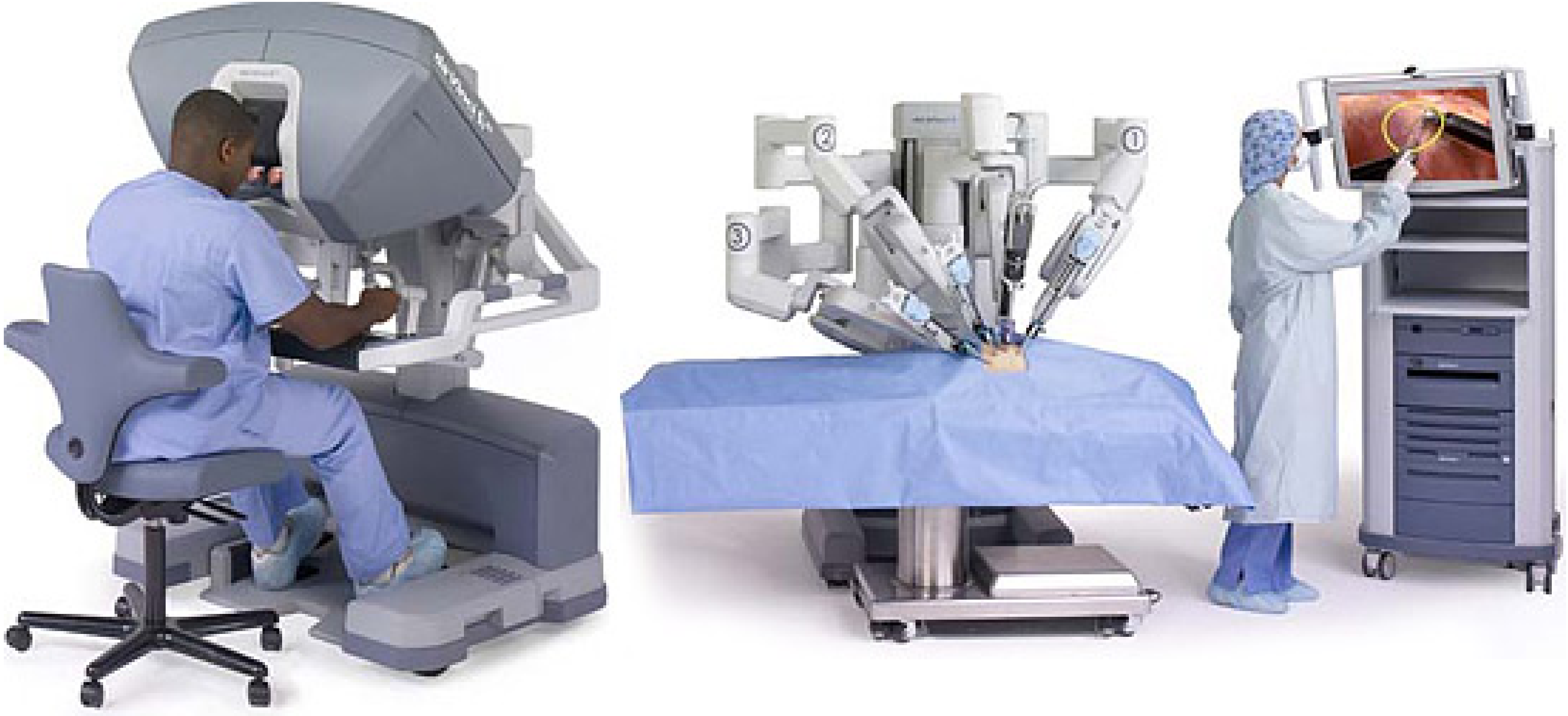

PUMA 560, 1985


ZEUS, 1999


PROBOT, 1988


AESOP, 1999

da Vinci surgical robot



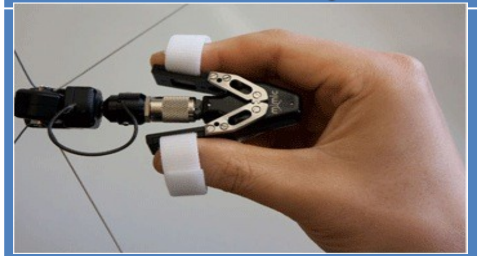
Electro-Mechanical Control, Digital Camera, Fiber Optics, Computer Science, Mini Instruments, Networking, Human Interface, Safety, Light Source, …

da Vinci simulators

Intuitive DVSS



Mimic dV-Trainer

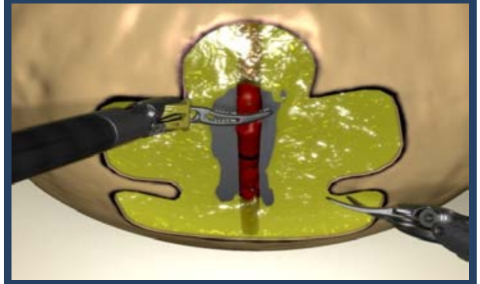




Sim Surg RoSS



Simbionix Robotix Mentor





More Robots on the Way

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Mako

Titan

Kumatoo

Medrobotics

Transenterix

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Google

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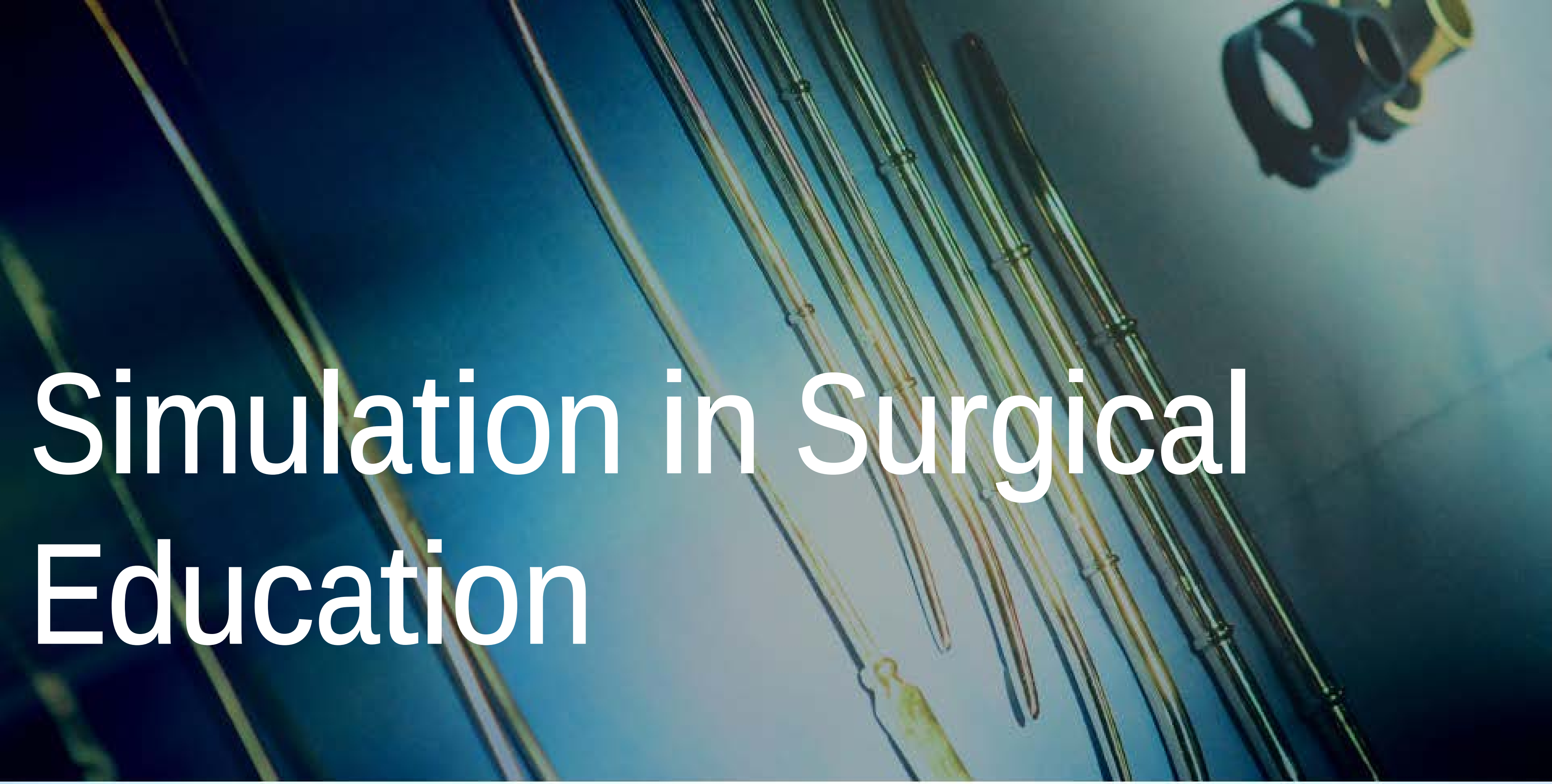
- **Cloud-based Surgical Guidance**
- **Machine Learning**

Thank You



Simulation in Surgical Education

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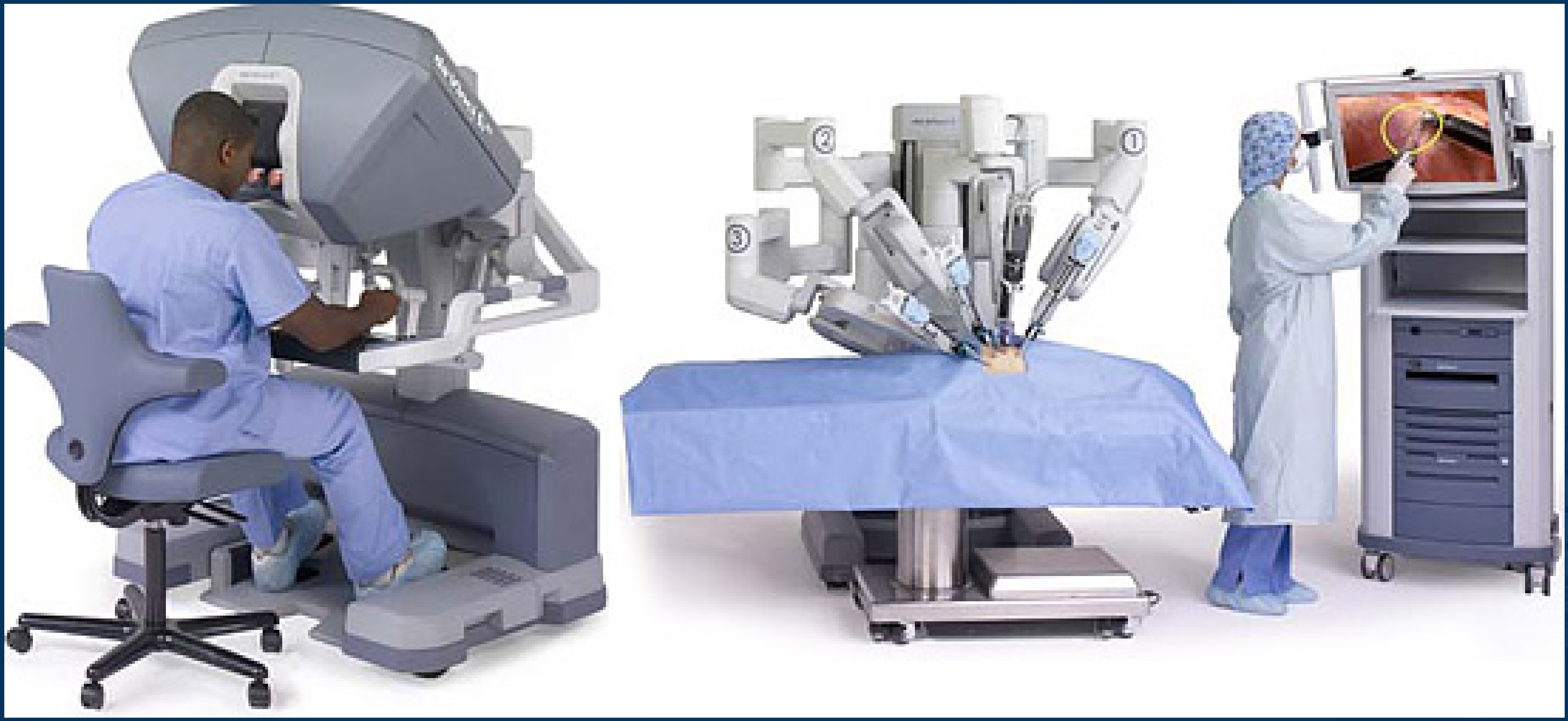
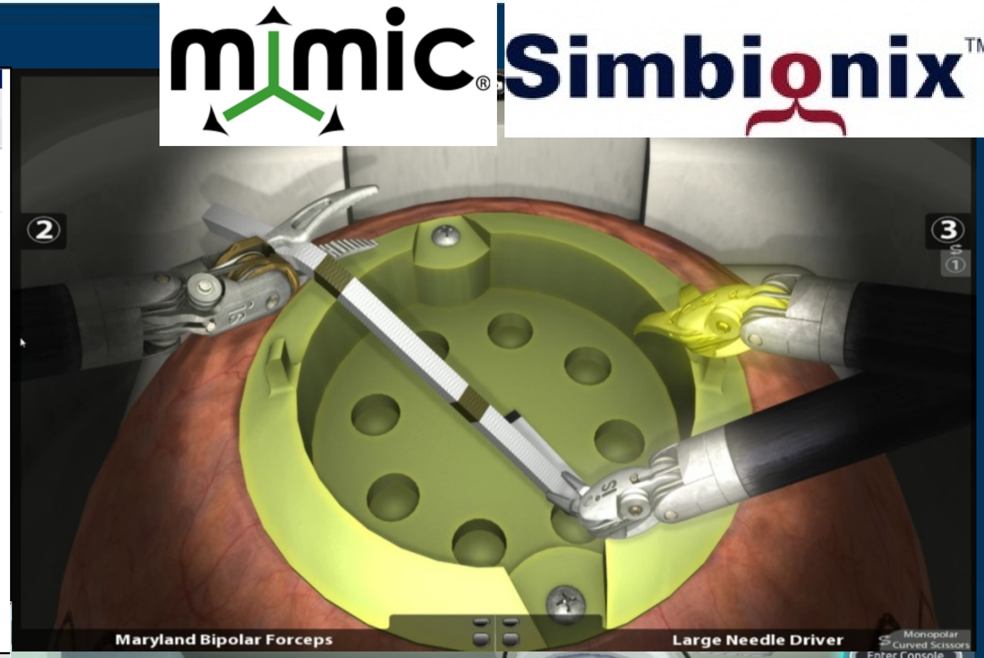
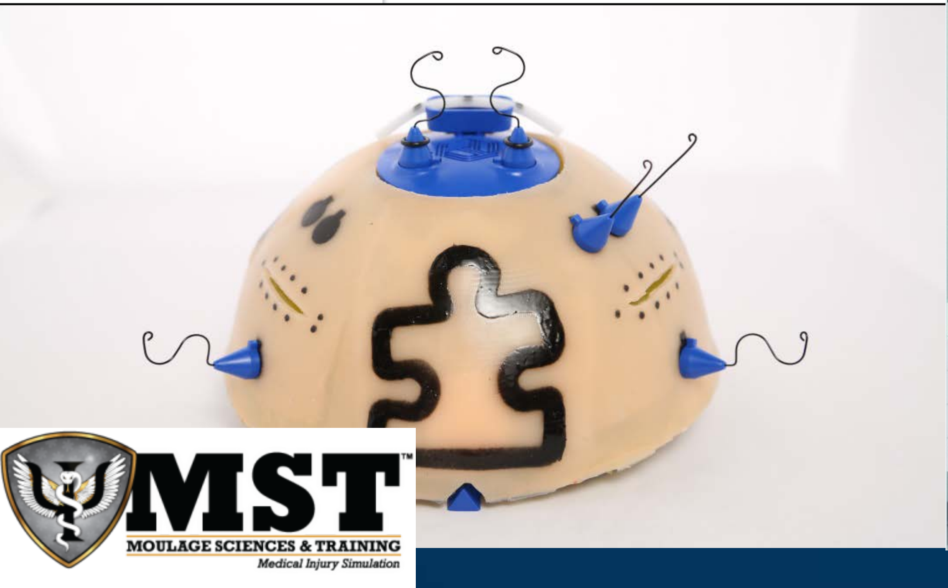
Fundamentals of Robotic Surgery

Create a validated multi-specialty, technical skills competency based curriculum for surgeons to safely and efficiently perform basic robotic-assisted surgery.



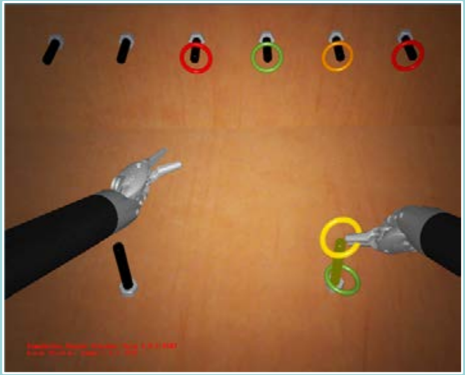
Video – Simulation - Device - Game



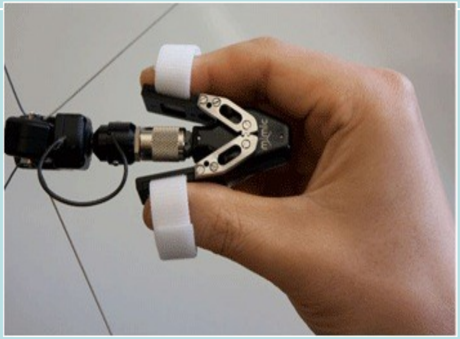


Simulators of the da Vinci Robot

Intuitive DVSS

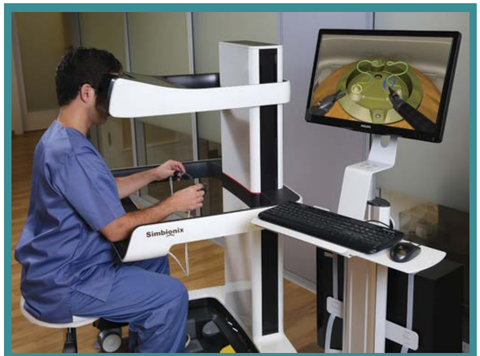


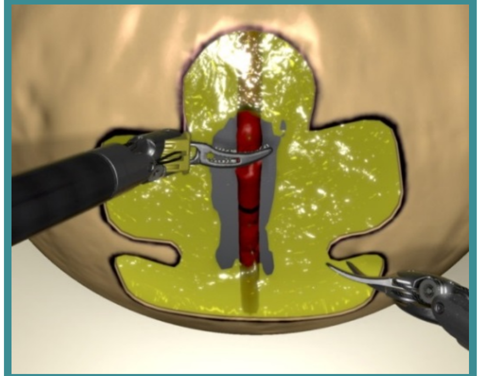
Mimic dV-Trainer



Sim Surg RoSS

Simbionix Robotix Mentor





Virtual Reality Robotic Simulation Performance Assessment: Simulator Metrics vs. GEARS

Study Objective: To compare the performance metrics of virtual reality (VR) robotic surgical simulators to the Global Evaluative Assessment of Robotic Skills (GEARS) metrics for basic robotic tasks. The goal was to determine if a difference exists between the scoring mechanisms of both validated tools for measuring surgical expertise.

Design: Prospective randomized study

Setting: Surgical education and training center

Patients: Residents, fellows, and attending surgeons (n=18)

Interventions: Participants were randomized to a specific order in which they used the dV-trainer and da Vinci Skills simulator (dVSS). The subjects performed two warm-up exercises: Pick & Place and Basic Camera Targeting and then completed two trials of Ring & Rail 1 (RR1) and Suture Sponge 1 (SS1) on each simulator. The simulator performance was video recorded and the de-identified videos were sent to expert robotic surgeons to review using GEARS.

Measures and Main results: The subjects' demographics can be seen in table 1. The second trial of RR1 and SS1 was used for video review and simulator evaluation. The ranges of individual simulator metrics were calculated and quintiles were identified. The simulator metrics were then categorized into the appropriate quintile, allowing comparison to the Likert GEARS scoring system.

In a preliminary analysis, the Economy of Motion simulator metric and the GEARS Efficiency metric were compared for both the dV-Trainer and dVSS. No differences were found between Efficiency and RR1 or SS1 in either system (Table 2).

Conclusion:
To our knowledge, no study has compared simulator metrics to video evaluations performed by experts. The preliminary data suggests that no difference exists between simulator scores and GEARS. Since the simulator's evaluation is similar to an expert robotic surgeon for basic tasks, this may indicate that a human evaluator may not be necessary for assessment of these skills. The final analysis is pending and will be completed by AAGL 2016.

Video Game Impact on Basic Robotic Surgical Skills

Alyssa Tanaka, M.S., Courtney Graddy, MHA, Manuela Perez, M.D., Ph.D., Khara Simpson, M.D., Mireille Truong M.D., Roger Smith, Ph.D

Study Objective: To compare the performance of "expert" video gamers to medical students, "laypeople," and expert robotic surgeons in a robotic surgery simulator.

Design: Prospective study.

Setting: Surgical training centers, medical schools, and videogame colleges.

Participants: Video gamers (n=40), medical students (n=24), laypeople ((n=35) and robotic surgeons (n=6) were recruited.

Interventions: Subjects completed a demographic questionnaire and three computer-based perceptual tests: a Flanker compatibility task, subsidizing task, and Multiple Object Tracking. Participants performed two warm-up exercises and eight trials of two exercises (i.e. Ring & Rail 1 and Basic Suture Sponge) on the Mimic dV-Trainer. Participants then completed the NASA Task Load Index and a post-questionnaire.

Measurements and Main Results: Gamers improved significantly from trial one to trial eight for all metrics in Ring & Rail 1 (Overall Score (OS) $p=0.000$; Economy of Motion (EoM) $p=0.000$; and Time $p=0.000$) and Suture Sponge (OS $p=0.000$; EoM $p=0.000$; and Time $p=0.000$).

Surgeons performed better on trial one of Ring & Rail for all metrics (OS $p<0.05$; EoM $p<0.05$; and Time $p=0.002$). Gamers performed significantly better than laypeople on trial eight of Ring & Rail for Economy of Motion ($p<0.05$) and Time ($p<0.05$). Surgeons performed significantly better for all metrics (OS $p=0.000$; EoM $p<0.005$; and Time $p=0.00$) in the first and eighth trials (OS $p<0.05$; EoM $p=0.001$; and Time $p=0.000$) of Suture Sponge. Medical students outperformed gamers for Time ($p=0.05$) in the first trial. No other differences were found.

Conclusions: A preliminary analysis indicates that videogame experience may influence the acquisition of basic, but not complex robotic surgical skills. The results could have implications for surgical training and other fields, indicating that consideration should be paid to the application of skills developed through other technologies.

This study is ongoing and a final analysis will be available for presentation.

Video Game Experience and Basic Robotic Skills

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***Abstract*—Virtual reality simulators have emerged as valuable tools for standardized and objective robotic surgery skill training and assessments. In recent years the idea of using video game technology in surgical education for laparoscopy has also been explored, however few have attempted to make a connection between video game experience and robotic surgical skills. Thus, the current study aims to examine the performance of video gamers in a virtual reality robotic surgery simulator. Furthermore, the video gamers' performance was compared to that of medical students, expert robotic surgeons, and "laypeople." The purpose of this study is to demonstrate that video gamers acquire perceptual and psychomotor skills through video game play, similar to those used by robotic surgeons.**

Subjects completed a demographic questionnaire and performed three computer-based perceptual tests: a Flanker compatibility task, a subsidizing task, and a Multiple Object Tracking test. Participants then performed two warm-up exercises and eight trials of two core exercises on a robotic surgery simulator. After completing all trials, participants completed a post-questionnaire regarding their experience with the system. Expert video gamers (n=40), medical students (n=24), laypeople (n=42) and expert robotic surgeons (n=16) were recruited. Medical students and gamers were significantly faster than experts in the Flanker Task. The experts were significantly slower than the all other groups in the subsidizing task. Experts scored significantly higher, were significantly more efficient, and were significantly faster than laypeople, medical students, and gamers in the first trial of Ring & Rail 1 and Suture Sponge. In trial eight of the simulation exercises, the experts performed significantly better than most groups in all of the metrics.

Contrary to prior literature in laparoscopy, this study was unable to validate enhanced abilities of video gamers in a robotic surgery simulator. This study does further demonstrate that the transfer of skills developed through video game play is relevant to the surgical technique. This may be due to the differences of the systems and how the users interact within them. In a society where video games have become an integral past time, it is important to determine the role that video games play in the perceptual and psychomotor development of users. These findings can be generalized to domains outside of medicine that utilize robotic and computer-controlled systems, speaking to the scope of the gamers' abilities and pointing to the capacity within these systems.

Keywords—Video games; Surgery; Simulation; Virtual Reality

This research was supported by the U.S. Army's Telemedicine & Advanced Technology Research Center (TATRC) through grant W81XWH-11-2-0158. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of TATRC.

I. BACKGROUND

Robotic surgery is an innovative approach to surgery, which introduces a new dimension to the surgical toolbox. Many systems preceded the current state of medical robotics, all of which were developed with a universal goal of facilitating the human surgeon in performing easier and more standardized surgeries (Figure 1). As variations of medical robots emerged, the Defense Advanced Research Projects Agency (DARPA) was concurrently developing the Green Telepresence System [1][2].This system evolved from the idea of a surgeon performing a procedure from a location remote to the patient, a concept referred to as telesurgery. The ability to perform surgery-at-a-distance has not completely come to fruition; however, it was realized that this concept is valuable not only for surgeons separated from their patients by hundreds of miles, but also a layer of skin.

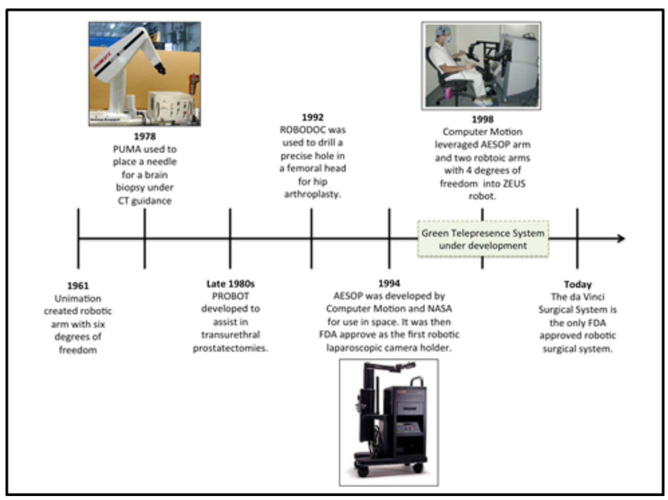


FIGURE I. History of surgical robotics

Currently the only FDA approved robotic system for a procedure on a human is Intuitive's da Vinci Surgical System. This system consists of three main components: the surgeon console, patient cart, and video tower. The surgeon manipulates the master controllers at the surgeon console, which is communicated to the patient cart through a fiber optic cable connection and moves the robotic arms in an identical manner (Figure 2). While this system offers many advantages over other minimally invasive surgery (MIS) techniques, it also introduces a need for specialized training. Virtual reality

(VR) simulators emerged as economical training tools that offer robotic surgeons standardized and objective skill training and assessments. In recent years, the role of video game technology in surgical education has also been explored.

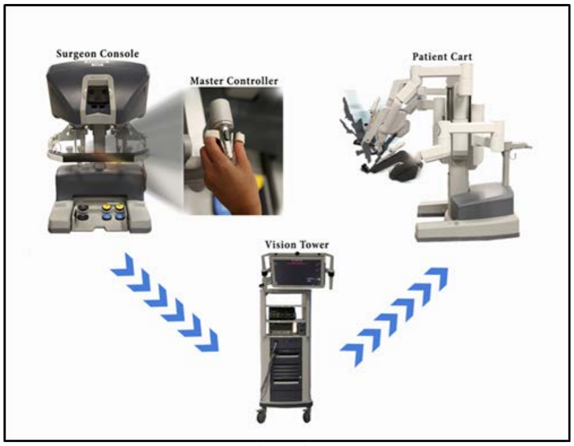


FIGURE II. Data flow from the da Vinci robot

Previous research has demonstrated that trainees with prior video game experience perform better on basic laparoscopic tasks in a dry lab and VR training environment [3][4][5][6]. Studies have also investigated using video games as training tools for laparoscopic surgery, many of which found positive training outcomes [7][8][9][10][11]. Certain genres of video games have established effects on perceptual skills similar to those required by robotic surgeons, yet few have attempted to make a connection between video game experience and robotic surgical skills [12][13][14][15].

Thus, the current study aims to examine the performance of video gamers in a VR robotic surgery simulator. Furthermore, the video gamers' performance was compared to that of medical students, expert robotic surgeons, and "laypeople." The purpose of this study is to demonstrate that video gamers acquire perceptual and psychomotor skills through video game play, similar to those used by robotic surgeons.

II. METHODS

A. Recruitment

Participants in this study included video gamers, expert robotic surgeons, medical students, and "laypeople" (i.e. individuals without formal medical education or extensive gaming experience). Gamers were recruited from a local university offering degrees specializing in game design and development (Florida Interactive and Entertainment Academy [FIEA]). Expert robotic surgeons were recruited from Florida Hospital, Florida Hospital Nicholson Center training courses, and at relevant surgical conferences. These individuals were surgeons who self-reported performing at least 100 robotic surgical procedures, of which at least 50% of the procedure was spent on the surgical console. Medical students were recruited from the University of Central Florida College of Medicine (UCF CoM) and laypeople were recruited from all data collection sites.

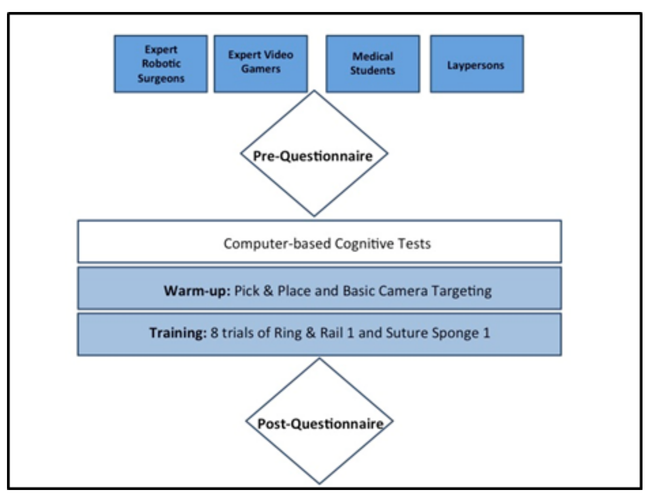
B. Design

All subjects completed a pre-questionnaire and then performed three computer-based perceptual tests: a Flanker compatibility task, a subsidizing task, and a Multiple Object Tracking (MOT) test. The Flanker compatibility test required the participant to indicate the orientation of a single arrow in the center of a group of several other arrows. The arrows are randomly generated to all face the same orientation (congruent) or the opposite direction (incongruent) of the target arrow in the center. This tests attentional capacity by requiring the subject to focus solely on the relevant arrow and ignore other stimuli. The subsidizing task also assessed attentional capacity by requiring subjects to identify the number of dots that appear on the screen as fast as possible. In the MOT task, users tracked specific objects as they move across the screen with other identical objects, which assesses visual attention (Figure 3).

FIGURE III. The cognitive tests

Participants then performed two warm-up exercises on a VR robotic surgery simulator, the Mimic dV-Trainer: Pick & Place and Basic Camera Targeting. This familiarized subjects with the system and system controls. All participants then performed eight trials of Ring & Rail 1 and Basic Suture Sponge to test various basic skills, which served as the primary sources for data analysis (Table 1). The Mimic dV-Trainer uses custom software and hardware to replicate the controls and viewing system of the actual surgical robot. This simulator was selected for this study from previously conducted research that confirmed the face, content, and construct validity of the system [16].

After completing all trials, participants completed a post-questionnaire regarding their experience with the system



(Figure 3).

FIGURE IV. Study design

TABLE I. Description of simulation exercises

Exercise	Purpose	Objective	Skills Trained
Warm-up Exercises			
Pick & Place	Introduction to using stereo vision and EndoWrist instruments for picking up and placing objects.	Place colored objects in matching colored containers.	Endowrist Manipulation
Basic Camera Targeting	Learn to accurately position the camera while working in a large workspace while practicing to keep the instruments in view and developing stereo depth acuity.	Manipulate the camera to position light blue sphere camera targets in the center of your screen's dark blue crosshairs.	Camera Control
Core Exercises			
Ring & Rail 1	Coordinate control of an object's position and orientation along a trajectory using the EndoWrist instruments	Pick up a ring and guide the ring along a curved rail	Endowrist manipulation, Camera Control
Basic Suture Sponge	Improve dexterity and accuracy when driving a needle through a deformable object.	Insert and extract a needle through several targets on the edge of a sponge with random variations in their positions.	Endowrist manipulation, Camera Control, Needle Control, Needle Driving

III. RESULTS

Video gamers (n=40), medical students (n=24), laypeople (n=42), and expert surgeons (n=16) were analyzed in terms of demographic characteristics. The participants were primarily male (66%) and predominantly right-handed (88%). The average age of all subjects was 29 (SD=7.559). Fifty-five percent of all participants reported that they currently play video games. The gamers reported having played video games for an average of eighteen years (SD=5.71) and playing an average of twelve hours per week (SD=6.74). On average, expert surgeons performed 135 laparoscopic (SD=94.55) and 95 robotic cases (SD=71.79) annually. Experts also reported performing an average of 1111 total laparoscopic cases (SD=725.41) and 624 total robotic cases (SD=607.13). Of the expert surgeons, 13% indicated that they currently play video games. Eighty-eight percent of expert surgeons reported that they have previously received formal robotic surgery training, with 94% of all expert surgeons indicating that have used a laparoscopic or robotic surgical simulator in the past.

A. *Perceptual Tasks*

Using a Kruskal-Wallis test, significant differences were found between the groups for the congruent time (H(3)=18.297, p<0.001) and incongruent time (H(3)=14.865, p<0.005) metrics. No differences were found between the groups for the percent correct (H(3)=1.107). When looking at pairwise comparisons for the congruent time metric, the medical students were significantly faster than the experts (p<0.05) and laypeople (p<0.005). The gamers were also significantly faster than experts (p<0.05). Medical students (p<0.005), and gamers (p<0.05) were significantly faster than experts in the incongruent time metric.

No significant differences were found between the groups for the percent correct metric in the subsidizing task (H(3)=5.296, p=.151). Using ANOVA, significant differences were found between the groups for the time metric in the subsidizing task (F (3, 115)=4.711, p< .005). A Tukey post-hoc test revealed that the lay people (991.94 ± 138.00 sec, p<.05) and experts (1058.59 ± 120.87 sec, p<.005) took significantly more time than the gamers (921.40 ±116.87 sec) to complete the task. The experts (1058.69 ± 120.87 sec, p<.05) were also significantly slower than the medical students (957.99 ± 148.45 sec). Using a Kruskal-Wallis test, differences were found for the difficult level (p<0.05) of the MOT. No differences were found for the easy and normal levels (p=0.656 and p=0.130 respectively). No significant pairwise differences were found for the groups (Table 2).

B. *Simulation Trial One*

Using a Kruskal-Wallis test, differences between the groups were found for the Overall Score (H(3)=12.90, p<0.01), Economy of Motion (H(3)=20.28, p<0.001), and Time to Complete (H(3)=32.55, p<0.001) metric of trial 1 of Ring & Rail 1. When looking at pairwise differences, experts

scored significantly higher than laypeople (p<0.005), medical

TABLE II. Descriptives for the cognitive scores

	Flanker			Subsidizing	
	Percent Correct	***Congruent Time***	***Incongruent Time***	***Percent Correct***	***Time***
Gamers	100.00 (IQR=5.00)	428.59 (IQR=72.66)	484.32 (IQR=83.10)	81.39 (IQR=15.99)	921.40 (SD=116.87)
Medical Students	100.00 (IQR=2.50)	414.92 (IQR=56.10)	466.25 (IQR=95.38)	76.19 (IQR=22.65)	957.99 (SD=148.45)
Laypeople	100.00 (IQR=5.00)	439.91 (IQR=85.47)	509.73 (IQR=74.23)	76.19 (IQR=16.66)	991.94 (SD=138.00)
Experts	100.00 (IQR=5.00)	476.40 (IQR=99.80)	560.27 (IQR=91.25)	76.19 (IQR=19.38)	1058.87 (SD=120.87)

TABLE III. Descriptives for Trial 1 of the simulation exercises

		Ring & Rail 1			Suture Sponge		
Category	***n***	***Overall Score***	***Economy of Motion***	***Time to Complete***	***Overall Score***	***Economy of Motion***	***Time to Complete***
Gamer	40	614.94 (IQR=537.37)	69.08 (IQR=25.74)	67.02 (IQR=35.33)	439.26 (SD=170.63)	566.58 (IQR=356.98)	517.88 (IQR=307.11)

TABLE IV. Descriptives for Trial 8 of the simulation exercises

		Ring & Rail 1			Suture Sponge		
Category	***n***	***Overall Score***	***Economy of Motion***	***Time to Complete***	***Overall Score***	***Economy of Motion***	***Time to Complete***
Gamer	40	1142.27 (IQR=42.63)	50.61 (SD=14.20)	29.24 (SD=10.12)	716.30 (IQR=537.76)	296.57 (IQR=102.45)	250.72 (SD=65.02)
Medical Student	24	1143.75 (IQR=74.89)	52.04 (SD=16.71)	28.64 (IQR=10.99)	939.84 (IQR=580.61)	306.42 (SD=76.12)	225.67 (SD=48.17)
Lay people	42	1108.06 (IQR=74.62)	62.25 (SD=18.91)	33.37 (IQR=17.66)	695.93 (IQR=587.58)	304.34 (IQR=92.75)	219.14 (IQR=109.02)
Expert Surgeon	16	1161.96 (IQR=64.79)	36.38 (IQR=10.87)	21.83 (SD=6.97)	1277.64 (IQR=117.54)	210.04 (SD=54.72)	135.67 (SD=40.83)

students (p<0.05), and gamers (p<0.05) in the Overall Score metric. Experts were significantly more efficient than medical students (p<0.005), gamers (p<0.001), and laypeople (p<0.001) in the Economy of Motion metric. Experts were significantly faster than laypeople (p<0.001), medical students (p<0.001), and gamers (p<0.001) in the Time to Complete metric.

Significant differences were also found for the Overall Score (H(3)=28.31, p<0.001), Economy of Motion (H(3)=31.15, p<0.001), and Time to Complete (H(3)=39.62, p<0.001) metrics for the Suture Sponge exercise. When looking at pairwise differences, experts scored significantly higher than gamers (p<0.001), laypeople (p<0.001), and medical students (p<0.005) in the Overall Score metric. Experts were significantly more efficient than medical students (p<0.001), laypeople (p<0.001), and gamers (p<0.001) in the Economy of Motion metric. Experts were significantly faster than medical students (p<0.001), laypeople (p<0.001), and gamers (p<0.001) in the Time to Complete metric (Table 3).

C. *Simulation Trial Eight*

Significant differences were also found among the groups for the Overall Score (H(3)=10.65, p<0.05), Econom3y of Motion (H(3)=20.99, p<0.001), and Time to Complete (H(3)=21.85, p<0.001) metrics for trial 8 of the Ring & Rail 1 exercise. When looking at pairwise differences, experts scored significantly higher than laypeople (p<0.05) in the Overall Score metric. Experts were significantly more efficient than laypeople (p<0.001) in the Economy of Motion metric. Experts were significantly faster than gamers (p<0.05), medical students (p<0.05) and laypeople (p<0.001) in the Time to Complete metric.

The groups also demonstrated significant difference for the Overall Score (H(3)=22.79, p<0.001), Economy of Motion (H(3)=23.62, p<0.001), and Time to Complete (H(3)=32.48,

p<0.001) metrics for the Suture Sponge exercise. When

looking at pairwise differences, experts scored significantly higher than laypeople (p<0.001) and gamers (p<0.005) in the Overall Score metric. Experts were significantly more efficient than medical students (p<0.005), gamers (p<0.001), and laypeople (p<0.001) in the Economy of Motion metric. Experts were significantly faster than medical students (p<0.001), laypeople (p<0.001), and gamers (p<0.001) in the Time to Complete metric (Table 4).

D. *Simulation Skill Acquisition*

A closer evaluation of the groups' ability to acquire basic robotic skills over the eight trials was conducted to evaluate if any one group improved significantly more than other groups. The difference between trial 1 and trial 8 was calculated for each participant and determined as the amount of change. A Kruskal-Wallis test was then used to determine if the amount of change was different between each of the groups. The groups demonstrated significantly different amounts of change for the Overall Score (H(3)=8.30, p<0.05) and Time (H(3)=25.84, p<0.001) metrics in the Ring & Rail 1 exercise. No differences were found between the groups for the Economy of Motion metric in Ring & Rail 1 (p=0.062).

When looking at pairwise comparisons, no differences were found for the Overall Score metric. Experts decreased their time significantly less than gamers (p<0.001), medical students (p<0.001), and laypeople (p<0.005) in the Time to Complete metric. Significant differences were also found between the groups for the Economy of Motion (H(3)=15.35, p<0.005) and Time (H(3)=24.78, p<0.001) metrics of Suture Sponge. No differences were found for the Overall Score metric. When looking at pairwise differences, experts improved their efficiency significantly less than gamers (p<0.005), medical students (p<0.05), and laypeople (p<0.05) for the Economy of Motion metric. Experts reduced their time significantly less than gamers (p<0.001), laypeople (p<0.001), and medical students (p<0.005) for the Time to Complete metric.

IV. Conclusions

Contrary to previous findings in laparoscopic research, the results of the current study were unable to confirm a relationship between playing video games and increased abilities in a robotic surgery simulator. The video gamers in this study did not perform better than laypeople or medical students in the perceptual tests. The expert surgeons outperformed all other groups in the first trial of the simulation exercises. They scored significantly higher, were significantly more efficient, and significantly faster than all other groups in the Ring & Rail 1 and Suture Sponge exercises. The gamers scored higher and were more efficient than medical students and lay people in Ring & Rail 1, but the differences were not significant. The gamers scored a lower score, were less efficient, and were slower than the medical students and laypeople in the Suture Sponge exercise.

Experts scored significantly higher and were significantly more efficient than laypeople for the eighth trial of the Ring & Rail 1 exercise. The experts were also significantly faster than all other groups. Gamers and medical students surpassed laypeople in the Overall Score, Economy of Motion, and Time to Complete metrics, although the differences were not significant. In the Suture Sponge exercise, experts scored significantly higher than gamers and laypeople. The experts were also significantly more efficient and faster than all groups in this exercise. The expert surgeons improved significantly less than the other groups for the Time metric of Ring & Rail 1 and the Time and Economy of Motion metrics in the Suture Sponge exercise. It is likely that the experts have less room for improvement because they are already proficient in the tasks.

While these results are conflicting with laparoscopic research, they align with the few studies that have examined the impact of video game play on robotic surgical skills [14][15]. So why does prior video game experience impact basic laparoscopic skills, but not robotic? Differences may be attributed to the distinctness of the systems in which the users are interacting. The skills developed in two-dimension video games may transfer more appropriately to laparoscopic surgery, which uses a two-dimensional screen, as opposed to the three-dimensional view in robotics. Laparoscopy also involves contrasting movements to the primarily fine motor movements of robotic surgery and it is possible that gamers are more inclined with the manual dexterity associated with laparoscopy. The movements associated with robotic surgery are also more intuitive than the proprioceptive challenge that laparoscopy presents. It is possible that gaming skills give users an advantage to overcoming the psychomotor difficulties, while the robot's intuitive nature renders the advantage extraneous.

In a society where video games have become an integral pastime, it is important to determine the role that video games play in the cognitive, perceptual, and psychomotor development of users. This research emphasizes the criticality in evaluating the impact of video games, prior to making assumptions on associated effects. Similar to the claims that video games are linked to violent actions, associations made without scholarly evidence can create inaccurate social associations [17]. This study has further emphasized that the effect of video game play on surgical skills is nuanced by the surgical technique. The findings can be generalized to domains outside of medicine utilizing robotic and computer-controlled systems, speaking to the scope of the gamers' abilities and pointing to the capacity within these systems. The research regarding the use of video games for training in robotic surgery is nascent.

Future research should further delve into the differences of the performance of gamers in laparoscopic and robotic tasks. Comparing gamers in both modalities would highlight the differences in performance. Research should also investigate if video game experience allows for better retention of skills, particularly leading to less skill degradation during periods of inactivity.

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