Developing an Intelligent Tutoring System for Robotic-assisted Surgery Instruction

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ABSTRACT

Robotic-assisted laparoscopic surgery is an operative innovation that has sparked global interest. Over the last decade RALS cases have rapidly increased with over 750,000 robotic procedures completed in 2017. Until recently, Intuitive's da Vinci surgical system has been the only FDA approved robotic-assisted surgical device for human procedures. Robotic procedures with the da Vinci require a specific, dedicated training due to the introduction of the technological components and psychomotor skills needed to successfully utilize this system. When a surgeon becomes interested in learning robotics there are limited avenues for training. Surgeons typically receive instruction on the necessary psychomotor skills in isolation from the cognitive and perceptual skills, and may only perform these skills in an integrated manner during a single day course.

In this paper we discuss the development of a computer based Intelligent Tutoring System to train the cognitive and procedural skills needed to complete basic robotic suturing to novice robotic surgeons. This system could be used to bridge the training gap between online cognitive training materials and hands-on psychomotor skills training with simulators and robots. The tutoring system could provide novice and intermediate robotic surgeons with intelligent guidance in an easily accessible system to train the cognitive processes and procedural steps behind multiple fundamental robotic surgery skills, to include instrument control, suturing, knot tying, cutting, and sharp dissection. This web-based intelligent tutoring system would serve as a precursor to more advanced tutoring systems, which would reside within a 3D virtual reality simulator of surgery.

This web-based intelligent tutoring system was developed using the Generalized Intelligent Framework for Tutoring framework of tools. The cognitive and psychomotor content for the system was collected from multiple practicing robotic surgeons who performed each tutored task using a simulator and explained their actions, reasoning, and potential mistakes as they performed each exercise. This information was captured as video, instruction sets, and flow charts, which were reviewed for accuracy by surgeons and then encoded into an intelligent tutoring system using the Generalized Intelligent Framework for Tutoring tools.

ABOUT THE AUTHORS

Danielle Julian, M.S., is a Research Scientist at Florida Hospital's Nicholson Center. Her current research focuses on robotic surgery simulation and effective surgeon training. Her current projects include an intelligent tutoring system, rapid prototyping of surgical education devices, and the evaluation of robotic simulation systems. She is a certified instructor for surgical robotics courses delivered to surgeons and OR staff members. Her background includes research in Human Factors and learning and training to enhance the higher-order cognitive skills of military personnel. She is currently a Ph.D. student in Modeling and Simulation at the University of Central Florida where she previously earned an M.S. in Modeling and Simulation, Graduate Simulation Certificate in Instructional Design, and a B.S. in Psychology.

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 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); Vice President (VP) and CTO for training systems at Titan Corp; and VP of Technology at BTG Inc. He holds a Ph.D. in Computer Science, a Doctorate in Management, an M.S. in Statistics, and a B.S. in Applied Mathematics. He has published 3 professional textbooks on simulation, 12 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

Over the last two decades the prevalence of Robotic-assisted Laparoscopic Surgery (RALS) has steadily increased within both military and civilian hospitals, reaching a total of over 3 million cases worldwide to date (Intuitive Surgical, 2017). This increase has generated a need for effective training for the unique skill set and technological knowledge required to successfully perform procedures with such advanced technology (Figure 1). This surgical method introduces a specific need for training and certification to ensure a minimal standard of care for all patients. Developing the ability to perform surgical procedures, with or without the robotic system requires mastering multiple skills. Required cognitive skills for surgeons include information recall, procedural knowledge, decision-making, and situational awareness. In addition to multiple cognitive skills, surgeons must master several perceptual skills essential to surgical performance, such as, visuo-spatial and perceptual-motor (e.g., depth perception) (Skinner et al., 2018).

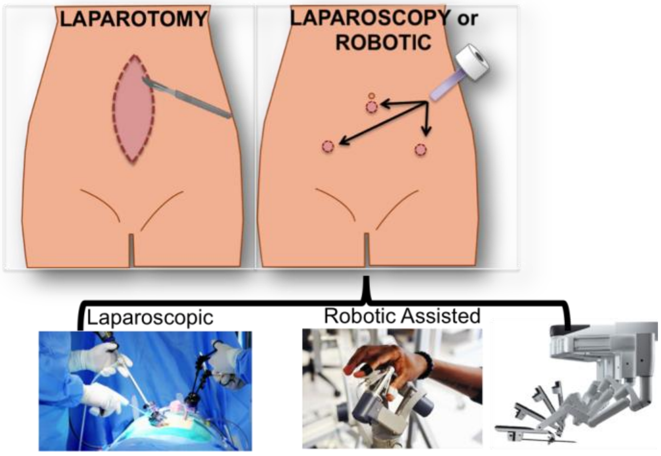

Figure 1. Current surgical modalities. Open (Laparotomy) vs. Minimally Invasive (Laparoscopy or Robotic).

The acquisition of cognitive skills has been studied extensively and research has shown learning curves typically involve three distinct stages of skill development: a cognitive stage, an associative stage, and an autonomous stage during which expertise is achieved (Anderson et al., 1997). For surgeons, these skills are learned through an extensively long educational program, including a four-year bachelor’s degree, four years of medical school, a three to five-year residency, and perhaps a two-year fellowship. For perceptual and psychomotor skills, RALS surgeons typically overcome this learning curve in an experiential way. Surgical trainees may encounter their first surgical experience on an inanimate training model, excised tissue, or an actual procedure with a mentor. While this method helps to improve performance with increased experience, these procedures usually take more time to complete and are associated with a greater number or errors, which may be life threatening to the patient.

More recently, Virtual Reality (VR) surgical simulators have been introduced to help alleviate this issue. VR simulation was first introduced to surgical education in the late 1980s (Satava, 1993). Since implementation, VR simulators have been established as a valuable training tool for the acquisition of basic surgical skills, allowing 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, such as Minimally Invasive Surgery (MIS) (Figure 2). However, these trainers can be expensive and are typically not portable which causes issues for practicing surgeons (e.g., Mimic Technology’s dV-Trainer or SimbioniX’s RobotiX Mentor). Acquiring more knowledge and skills by increasing the number of "in hospital" practice hours is not possible. One alternative is to improve the methods of training through more efficient and readily available training methods.

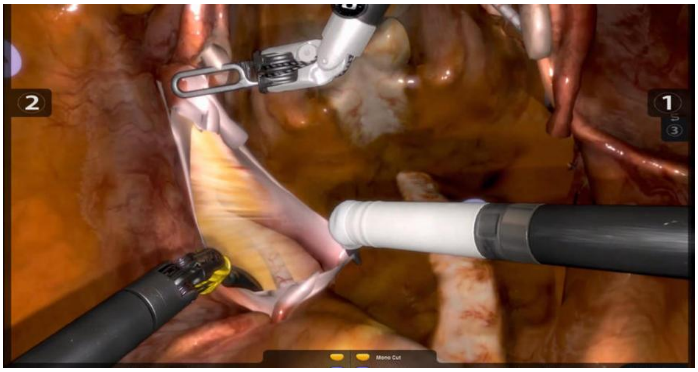

Figure 2. Example of virtual human anatomy in a VR surgical simulation. Dissection of the Ureter during a robotic Prostatectomy procedure.

Within the education and military training domains, Intelligent Tutoring Systems (ITSs) are used for teaching a variety of cognitive skills such as troubleshooting, problem solving, and resolving critical situations. An ITS continuously monitors, assesses, and provides feedback to students, just as a human trainer does. The tutoring system collects data on the learner's state of knowledge and then provides the appropriate level of instructional content and delivery to maximize the user's experience while utilizing embedded student models, task models, and instructional models (Skinner et al., 2018). Recently, research has showed the effectiveness of computer adaptive instruction as compared to traditional classroom and small group instruction (Skinner et al., 2018; Kulik & Fletcher, 2016).

Despite the effectiveness of ITSs in other domains, few fully developed applications of intelligent tutoring technologies have been created for medical training. Many of the current medical ITSs were created to teach knowledge-based medicine (Crowley et al., 2007) or to aid in image recognition. One of the earliest medical ITSs, GUIDON, trained medical students about infectious diseases like meningitis and bacteremia. The objectives were to identify likely causative organisms given a patient's history, medical records, and laboratory results (Clancey, 1986). It used an interactive mixed-initiative method of dialogue where either the student or the system could be in control of how the discussion played out (Clancey, 1986; Crowley et al., 2007). Another system, MR Tutor, is a case-based tutoring system that focuses on case similarities across patient instances. This system uses a library of radiologic images where the tutor applies statistical indices to find similarities across the collection (Sharples et al., 2000).

More recently there have been several tutors developed to train on specific diseases, including diabetes and stomach disease (Almurshidi & Naser, 2017a; Almurshidi & Naser, 2017b). Almurshidi and Naser's (2017b) latest tutor aims to train medical students about multiple stomach diseases. This system allows the learner to navigate through numerous domains of multiple stomach disease with knowledge checks within each module. If the student scores a 75% or higher, they may move to the next level of difficulty, if not, they repeat the same set of exercises/content review. This method of recall and rehearsal provide repeated exposure to students that have yet to master the knowledge or skills. Other developed medical tutors include: teaching clinicians to draw conclusions from diagnostic reasoning (Voytovich, 1985), training clinicians to interpret mammograms (Azevedo & Lajoie, 1998), training diagnostic reasoning for antibody identification (Smith et al, 1998), teaching the interpretation of neuroradiological images (Sharples, et, 2000), training detection of diagnostic errors in internal medicine (Graber et al., 2005), teaching clinical medicine using various media (Martens, et al., 2001), and teaching medical students to develop high level pedagogic strategies (Yudelson et al., 2008).

This paper describes the efforts to design an ITS for RALS using a web-based authoring system, the Generalized Intelligent Framework for Tutoring (GIFT) authoring tool. The paper explains (1) the process used to obtain the critical data behind a basic robotic task, (2) the process used to develop an entry level ITS to train the cognitive process and procedural steps behind multiple fundamental robotic surgery skills, specifically for the da Vinci surgical system (Figure 3), and (3) provides future novice developers with lessons learned and recommendations from the initial ITS prototype.

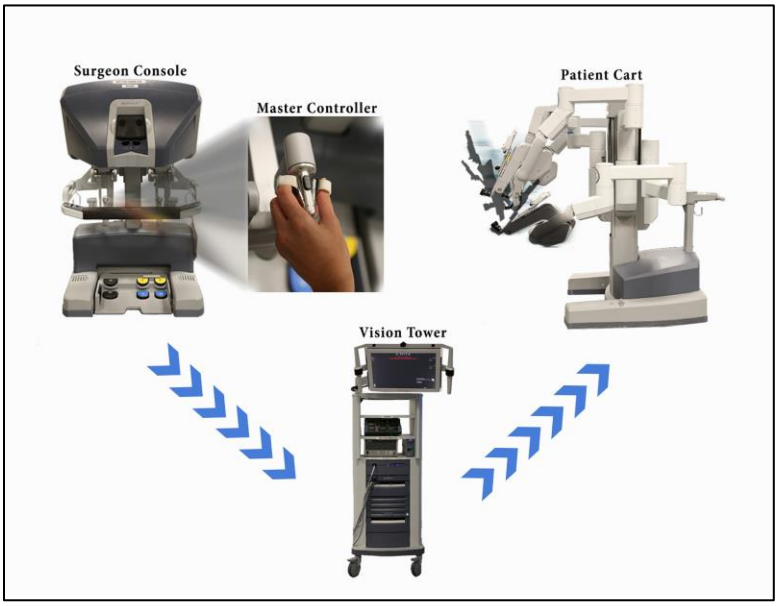

Figure 3. Three components of the da Vinci Surgical System: Surgeon Console, Patient Cart, and Vision Tower. The surgeon manipulated the controllers located on the surgeon console, which sends information to the vision tower that is then translated into movements of instruments located on the patient cart.

METHODOLOGY

To create the initial tutoring system, the ADDIE (Analyze, Design, Develop, Implement, and Evaluate) process was used for the design and development of the learning application (Branch, 2010), including a literature review of current medical intelligent tutors. The literature review showed a gap in medical surgical tutoring systems and helped to outline the problem. Motivated by this training need, a modified task analysis was created, described later in this section, to capture the intricacy within the interaction of cognitive, psychomotor, and perceptual skills required to complete the robotic tasks. The content for the task analysis was collected from multiple practicing robotic surgeons, who performed the tutored tasks using a simulator while a researcher scribed their actions, reasoning, and potential errors. This data was captured via video recording, instructional sets, and flow charts which were then reviewed by Subject Matter Experts (SMEs) and used to guide the instructional content used within the ITS. This process is explained in more detail later in this paper.

Analysis of the Problem

The RALS domain represents a complex task environment involving cognitive, perceptual, and psychomotor skill components; which could greatly benefit from real-time assessment and adaptive instructional capabilities. Integration of ITS components into a RALS-based course could support a reduction in both self-guided and instructor-led training, and could accelerate the skill acquisition process for novice surgeons, directly benefiting patient outcomes. In addition to initial acquisition training, such a curriculum could be applied as refresher training after periods of nonuse. In an attempt to provide surgeons with a portable, customizable, accessible trainer that offers immediate feedback, we developed a web-based ITS pilot to train surgeons basic robotic surgical skills needed to successfully utilize the da Vinci surgical system.

Analysis of the Users

There are two primary users for this tutor. The first are residents, fellows, or attending surgeons that wish to start practicing as robotic surgeons. The second are experienced robotic surgeons that need skills refreshment. Both groups of users will have limited self-training time. 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 learner 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, which can be approved for use across the corporate environment.

Analysis of the Tasks

Skinner et al. (2018) developed a modified task analysis technique which builds on an established Cognitive Task Analysis (CTA) method developed by Cannon-Bowers et al. (2013) which aids in outlining training requirements, metrics, and scenario needs simultaneously. This Multi-Modal Task Analysis (MMTA) requires experts to perform the task at hand multiple times. All iterations explore a different element of the training development process. Expert and novice robotic surgeons, as well as expert simulation instructors, were asked to complete basic robotic skills on a simulator. Researchers and analysts elicited information from the subjects while they completed the basic robotic surgical tasks. This process is discussed in more detail later in this paper.

Design of Instruction

The basic robotic material was leveraged from the Fundamentals of Robotic Surgery (FRS), a multi-specialty robotic surgical skills curriculum created with help from over 80 SMEs (Smith, Patel, Chauhan, & Satava, 2013). The curriculum contains online cognitive training material, a physical psychomotor skills device for assessment, and a team-training component. Portions of the basic cognitive material were used to provide the learner and tutor with an introduction of the da Vinci system. Of specific interest for the current work is the psychomotor skills curriculum that is comprised of six basic training tasks. More specifically, this project incorporated two of the six tasks – i.e., camera targeting and suturing (Figure 4). The material was then modified to include the SMEs' input on both the cognitive and psychomotor skills documented during the recorded exercise trials. The instruction for the ITS was developed from both the available FRS curriculum and the collected data from SMEs.

FRS Task 3 Railroad Track The trainee must perform horizontal mattress suturing through a series of target points to approximate the tissue, followed by anchoring the needle by passing it through the final two target points twice.	**Primary Skills:** Holding and manipulating the needle; Following the curve of the needle; Utilizing the full range of motion of the endowrist; Using graspers **Secondary Skills:** Eye hand instrument coordination; Passing objects between instruments; Appropriate handling of suture material; Running suture

Figure 4. Psychomotor Suturing Exercise from the FRS Curriculum.

Design of User Experience

The instructional environment was provided through a cloud-based authoring system called GIFT. GIFT allows instructors with little to no programing experience to build adaptive training functions and ITSs. This ITS developed with GIFT provides the learner with an adaptive course that includes a demographic survey, pre-test/post-tests, knowledge assessments, tailored feedback, textual information, videos, multimedia-based instruction, interactive conversation trees, and data collection. GIFT is also an instructional manager that integrates selected instructional theory, principles, and strategies within an ITS (Fletcher & Sottilare, 2013; Sottilare, Ragusa, Hoffman & Goldberg, 2013). The material used within the ITS was collected via the MMTA, actual footage of a VR simulated procedural exercise, and material from a pre-existing validated curriculum (e.g., FRS). The primary goal of the environment is to lead the learner through the course material and assist them in understanding correct actions that should be applied when transferring knowledge and skills to their next step of training, typically a VR surgical simulator or actual surgery. This ITS can be used as both as a learning environment and an assessment tool.

Development of Evaluation Criteria

This tutor is structured to provide the following:

1. Introductory information on surgical robots,
2. Technical details on the da Vinci surgical system,
3. Basic camera control knowledge, and
4. Limited introduction to suturing with the da Vinci system.

This iteration of the system uses a mastery learning technique to ensure the learner has satisfactory recall and can apply perquisite knowledge before proceeding to the next concept to be covered.

Before the course begins, the learners must complete a demographic survey. This survey is used to collect information about the learners, their specialty, and experience level. This iteration of the system used a demographic survey to collect information only and is a non-actionable questionnaire. As other iterations are developed, the demographic questionnaire may be used as an actionable survey that could affect the flow of the course content. For example, if the learner has selected otolaryngologist (i.e., Ear, Nose, and Throat surgeon) as their specialty the course environment can take action to provide material for this specialty. In this case, ENT surgery requires little suturing and more energy application (e.g., cauterization), so the suturing content will not be as imperative to this student as others.

Due to the ambiguous training associated with surgical robotic programs, the course will provide a mandatory actionable knowledge assessment (Figure 5). This assessment is used to measure the learner's prior knowledge on the course objectives. At least one question from each course concept listed above is covered in this assessment.

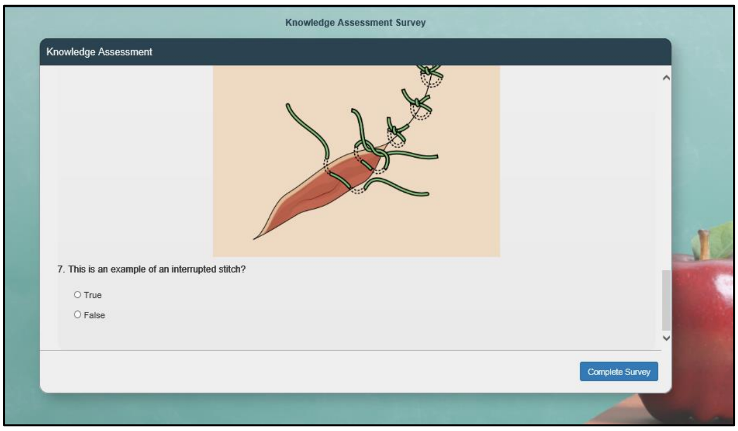

Figure 5. Example of a Knowledge Assessment within ITS.

The tutoring system utilizes the information collected during the initial knowledge survey to adapt the users course material. If the user scores < 20% on the initial knowledge assessment, the course will flex to provide novice-based foundational content with more engaging and detailed material (e.g., complete videos) for the subsequent module. Consequently, if the user scores anywhere between 20-70%, the user is considered a "Journeyman" and will be provided with less tailored material within the next module (e.g., diagrams, specific video clips). If the learners were classified as "Experts" (>70%) the course will adapt to show more concise textual content.

A SME developed the questions and scoring scale. Benchmarking these scores will be part of a future validation process in which these proficiency levels will be tested among novice, intermediate, and expert surgeons.

Implementation of Training

The prototype of the ITS for RALS will be implemented in multiple steps. The initial version will be available to the SMEs and supporting staff, which assisted in the development of the curriculum and completion of the task analysis. This iteration of deployment will allow those involved to provide feedback during the early releases and aid in redesigning any features of the preliminary application. The application will then be released to a community of expert robotic surgeons who have contributed to the creation of the FRS material used for curriculum development and faculty of an existing robotic training course. These experts will provide feedback and become the conduits for sharing the ITS with aspiring robotic surgeons, hospital systems interesting in creating a robotics program, and for potentially implementing it into the current robotic training courses. After an initial rollout to the established robotic program, the research team must revisit the expenses related to the maintenance of the ITS before making the application publically available at no cost.

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 validation trial of the tool with the goal of demonstrating that it is an equal or better method of teaching fundamentals of robotics and basic robotic skills than the existing methods. Once the application is complete, the tutoring system can be used at an established robotic course, which will allow practicing robotic surgeons, international surgeons, and robotic faculty to test the validity of the content and system.

DEVELOPMENT

Data Acquisition

The development process began with the acquisition of knowledge and data points that were later incorporated into the tutoring system. As mentioned previously, the research team conducted a MMTA to analyze the tasks and elicit information from SMEs. For the MMTA associated with this project, the following steps were completed:

> *1. Review the available RALS content.* This included information on the da Vinci Surgical System (e.g., technical manuals), documentation about the GIFT application, review of the FRS curriculum, and best practices established through practicing experts.
>
> *2. Utilize Subject Matter Experts and Novice Robotic Surgeons.* SMEs were domain experts including instructors with expertise with the simulation tasks being analyzed, expert robotic surgeons that reviewed each video recorded task, and novice robotic surgeons to provide additional instruction and feedback.
>
> *3. Task Decomposition.* Novice robotic surgeons were video recorded completing a suturing task on a robotic surgical simulator for the da Vinci system (i.e., SimbionX's RobotiX Mentor). To complete this task suturing, needle holding, needle driving, and camera targeting skills were required. While the task was being completed, instructors provided real-time guidance and instruction on successfully completing the simulated task. Researchers asked the instructor questions regarding tips, tricks, and suggestions to completing the simulated exercises. Instructors were then asked to complete the same exercise while explaining each move, decision, and rationale. This information was also video recorded and scribed. The recorded performance from both the novice surgeons and instructors (expert) were then reviewed by researchers, instructors, and expert robotic surgeons to map decision points and correct/incorrect moves.
>
> *4. Test task decomposition.* The SMEs were then asked to complete the task again while the task analysts asked questions to elicit critical cues at each step of the task. The answers to the prompted questions were documented and used in completing the MMTA.

From the adapted cognitive task analysis, the research team created several task flow diagrams (Figure 6) and task decomposition tables (Skinner et al., 2018) to outline the actions and decisions a surgeon must make to complete a simple suturing exercise. While the scope of this project at this time does not include all 33 standard path actions and 11 decision points found throughout the analysis, the MMTA provided the research team with the basic cognitive and psychomotor content needed to develop the first iteration tutoring system. Later iterations could potentially use the full decomposition data for computer algorithms, which could provide a task specific scoring system of the exercise and an intelligent, automated instructor for learners using the VR simulator used to capture the data.

While every action and decision point has not been integrated into the current tutor, this iteration provides users with several images and videos that deliver information on acceptable camera placement and suturing skills outlined by the MMTA. This version of the computer-based tutoring system provides the learners with the basic procedural steps needed to appropriately align the camera (e.g., camera placement, clear visual of target anatomy) and essential skills for completing a specific suturing task (e.g., correct needle grasp, appropriate needle throw target).

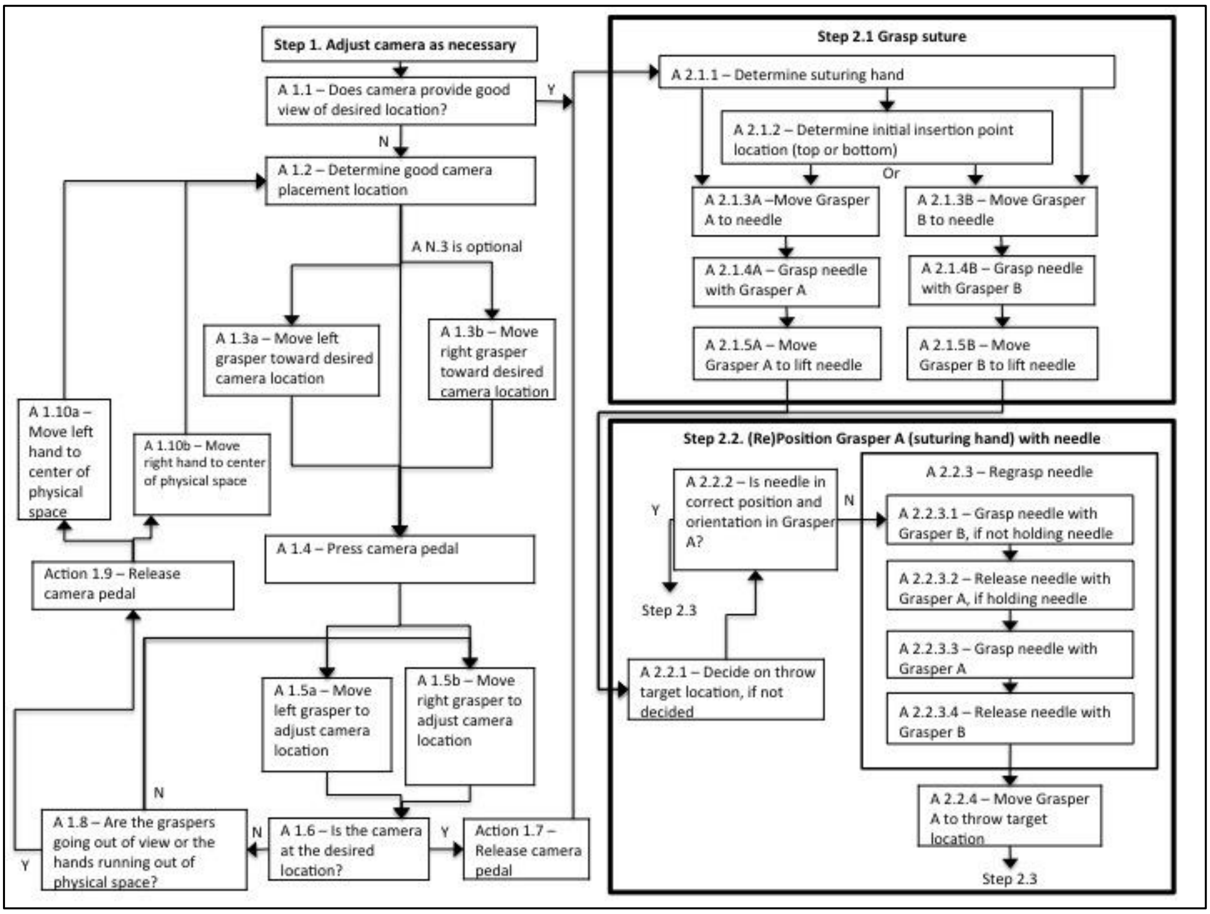

Figure 6. Snapshot of Task Flow Diagram.

RESULTS

The GIFT suite was selected because it utilizes changes to the learner's state (cognitive, affective, physical) to select appropriate instructional strategies (plans for action by the tutor) (Sottilare, Graesser, & Hu, 2013) in a simple "drag and drop" or "plug and play" way. Specifically, changes in the learner's state (i.e., knowledge or engagement) send messages to the pedagogical model within GIFT, which then recommends courses of action to the specific domain module (i.e., a robotic course) to provide a domain specific intervention (Sottilare, Graesser, & Hu, 2013). GIFT is cloud-based and designed to be user friendly for a variety of educators with little to no programming knowledge. Because the material was developed by expert surgeons and surgical instructors to be used within a hospital network, we felt that GIFT provided our team with an intuitive program for developing this tutor. The following section provides a brief overview of the current RALS ITS course material.

Current Course Material

As mentioned previously, the da Vinci system now provides a piece of technology with which most practicing surgeons will have little experience. Before training the skillset to overcome this learning curve, the learners should be familiar with robotic surgery in general. The course starts with basic text explaining the difference between traditional Laparoscopic and RALS. This portion will be a short mandatory object of the course. The learner is presented with a basic overview and history review of the introduction of robotic surgery and how the da Vinci system was brought to fruition. Because the history of surgical robotics is extensive, a conversation tree was selected to help train this material and maintain learner engagement. The conversation tree uses looping pathways. The student selects which early robotic system they would like to learn about, then must select another from the list, eventually moving their way to the end of the tree.

The ITS systematically varies the presentation of instructional content based on the learner's level of expertise, as determined by the knowledge checks. If the learner's knowledge is classified as "Novice", the content is more engaging and shows diagrams/pictures. If the learners are classified as "Experts" the course adapts to show more concise textual content. Student's knowledge was the main attribute driving the course flow and content, while learner engagement, surveyed throughout the course, is a secondary user attribute. Figure 7 shows the course layout and flow.

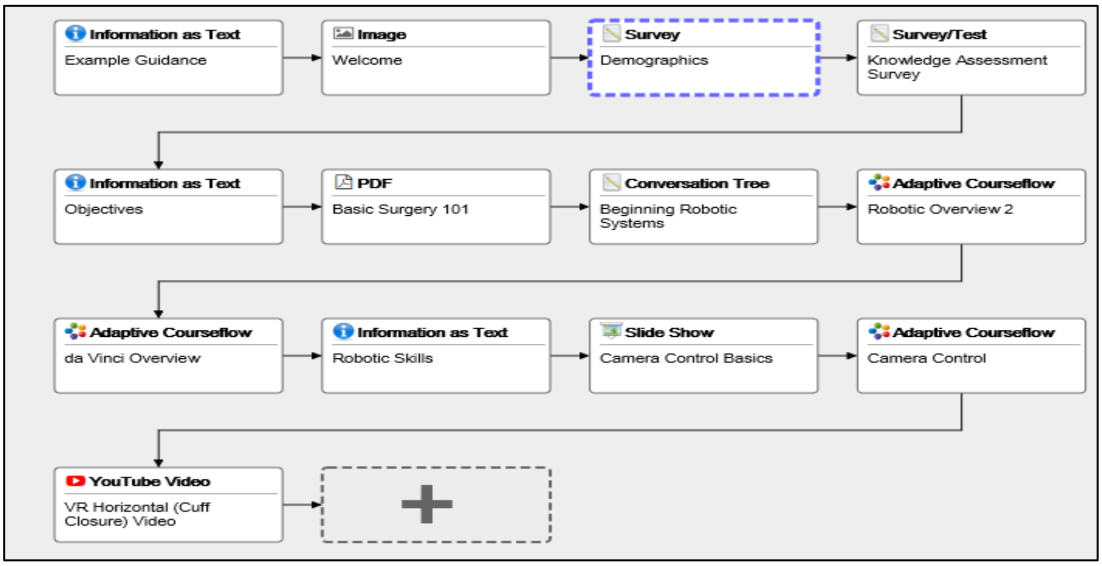

Figure 7. Overview of current course flow for ITS.

If the student does not do well on knowledge checks via a short questionnaire selected from a larger course question bank, then the student is provided with a more extensive version of the concepts.

The next learning objective trains the basic technical knowledge needed to use the actual da Vinci Surgical System. The answers collected from the introductory knowledge assessment drive the content for this section of the course as well. If the student scores poorly in the introduction assessment they are provided with a detailed, but more engaging (e.g., video overview) content delivery. In addition, if the learner scores "low" on the self-reported engagement survey offered in the beginning of the course, the learner's state will change the course content to the same detailed, engaging content. Consequently, if the learner does well on the opening assessment or scores "high" on the engagement survey, the tutor provides traditional textual, more concise content. After the initial mandatory content, the learners are provided with a short questionnaire to gauge their knowledge, leading back to the original or alternative training material if they scored poorly or moving them to the next concept if they scored well. This adaptive course flow helps to provide tailored content specific to the learner's existing and acquired knowledge and engagement with material.

To break up some of the textual content, multimedia technology is used to cover the basics of the next objective - Camera Control. Imagery and text are used to help maintain learner engagement and provide basic technical information regarding the camera scope for the da Vinci system (Figure 8). Image A (of Figure 8) provides the learners with a clear, centered image of the anatomical space. Whereas Image B shows a fogged image of the anatomy. The students are expected to select the optimal camera image (Image A) to move on to the next procedural step. The camera control adaptive course flow and the suturing content will need further development in order to provide valuable training in psychomotor skills. This content was also derived from the MMTA described in the early section. After being presented with the material, the learner must complete another knowledge check, utilizing images like those shown in Figure 8. If the student scores below the preset benchmarks, they will return to review or receive additional camera control content.

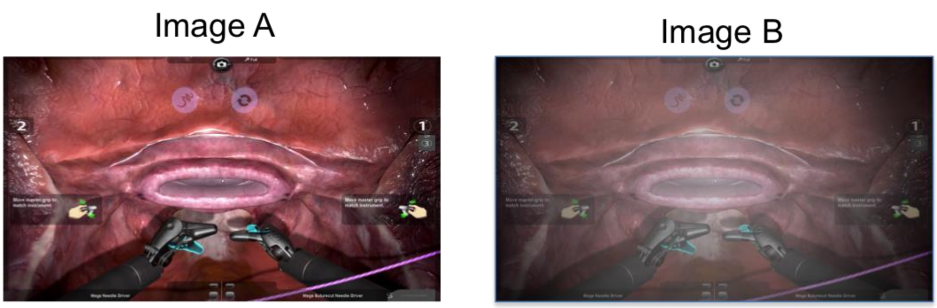

Figure 8. Example of Camera Control Content.

Before the tutor moves into training the steps, tips, and tricks behind the suturing skill set, a simulation video will play for all students. This video shows a vaginal cuff closure completed robotically with a surgical simulator. This procedure was chosen as course material because it requires camera movement and control and requires the surgeon to complete a cuff closure using an interrupted stitch. This stitch is common, but difficult for novice robotic surgeons. A video was selected to provide the learner with an all-encompassing example of what the tutor is aiming to train. The video shows why a technical overview of the system is imperative, the importance of camera control, and how an adequate interrupted suture in performed. The suturing material is shown via step-by-step procedural questions that demonstrate an improper image option and an optimal image option for each of the 11 decision points that were defined by the MMTA. For example, one action defined by the analysis is the appropriate grasp of the needle with grasper A. Figure 9 shows an example of an optimal needle grasp (Image B) versus a more difficult needle position (Image A). These types of images are used within the frequent knowledge checks. Students must choose the image that shows the optimal needle positioning to move to the next action. Later iterations will contain the 11 decision points *and* the 33 action paths outlined by the analysis.

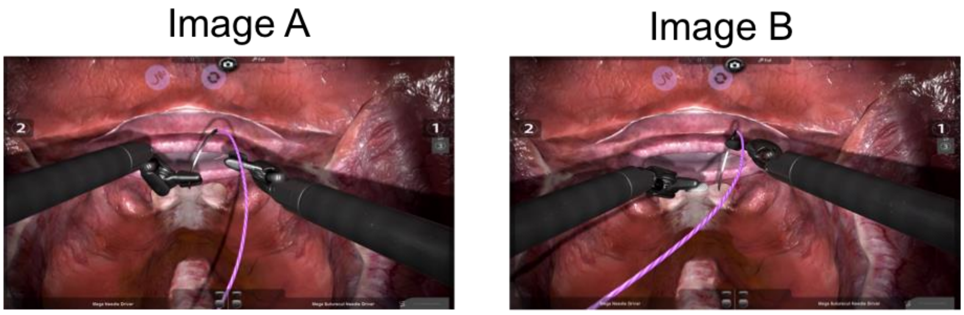

Figure 9. Example of Needle Control Content

DISCUSSION

During the development of the tutoring system, numerous issues, lessons learned, and future recommendations arose. The following section outlines several things to consider when creating an ITS using GIFT and for future iterations of the RALS ITS.

Lessons Learned

Need for Prior Knowledge and Experience. Using GIFT as the authoring tool for developing the cognitive concepts associated with robotic surgery was user friendly. The drag and drop concept was beneficial for course flow planning and content development. However, future iterations of the robotic tutor (including more psychomotor training) will be difficult for a developer with little programming experience or limited GIFT experience. For challenging content, the developer must be well versed with this authoring tool and would require extensive computer programming skills. Choosing such a complex topic to train is difficult within any tool because of the psychomotor skills, procedural knowledge, and variance of surgical specialties. For example, suturing for a general robotic surgeon will differ from suturing for a gynecological surgeon. The authoring tool offered multiple media outlets and supports a substantial amount of content, but a novice user may not know how to integrate the many “bells and whistles.” The robotic tutoring system could have benefited from including highlighting clues during assessments or interaction within a video.

Consider Method of Disseminating Training Content. When considering an authoring system for developing an ITS, like GIFT, it is important to consider who the end-users will be and in what environment the application will be used. Completing the instructional processes before considering which platforms to use for developing the tutor is imperative. For this system, the end-users are typically not proficient at installing new applications on computers and they will typically be using an assigned computer that is usually controlled by hospital IT restrictions. These limitations should be established before choosing which platform the ITS will be developed or hosted. Web- or Cloud- based training resolves many logistical problems regarding the distribution of training content.

Multi-Modal Task Analysis. The modified version of a CTA used here, MMTA, provided a detailed task decomposition for the complex psychomotor-procedural tasks we aimed to train utilizing an ITS. We believe this methodology can be used for other complex training domains that require cognitive, perceptual and psychomotor skills and knowledge. It may be applied for the development of ITS task models specifically as well as for conducting task analyses in general. While this methodology was applied to a suturing task, we aim to apply this technique to other robotic surgical skill sets in the future (i.e., energy application or robotic stapling).

Easy to Update and Maintain. GIFT will provide an easy platform for updating multimedia content. In addition, the student's data is stored within the GIFT system which means there is no need to run the tutoring system within an external Learning Management System. This makes the maintenance of the tutoring system and the collection of student data easier.

Future Recommendations

Design Content to Enable Sustainment Training. This iteration is aimed at training novice robotic surgeons. The content should be further enhanced so that the tutoring system has the ability to train the novice surgeons and to support periodic re-training, such as practicing robotic surgeons that wish to maintain their knowledge and skills between intervals of inactivity (e.g., military deployment). Content should be developed beyond basic robotic skills (e.g., suturing) for the specialties that utilize robotics the most (e.g., urology, gynecology, general surgery).

Incorporate Ways to Collect Additional Student Data. Future versions could integrate an "off-the-shelf" (e.g., Omni Phantom) controller to represent the master controller of the da Vinci system with embedded sensors. This will allow the tutor to collect user data for the purpose of constructing data-driven assessment logic within GIFT. Some sensor capabilities are already available within the GIFT system (e.g., EEGs, heart rate monitor, temperature). But with the correct equipment and staff, (i.e., programmer) pressure sensors could be incorporated to help collect data from the psychomotor skills required to complete the robotic tasks to provide learners with real-time feedback in consideration of the psychomotor movements. The sensors could also potentially trigger instructional events.

Integrate GIFT into VR Surgical Simulator. The end-goal for the MMTA and tutoring system would be to incorporate the tutor into a pre-existing VR surgical simulator, such as the RobotiX Mentor developed by SimbioniX Ltd. The full decomposition data from the MMTA could potentially be used for computer algorithms, that could provide a task-specific scoring system of the exercises and an intelligent, automated instruction for learners using the VR simulator.

CONCLUSIONS

This paper summarizes the initial development process for creating a computer-based ITS for novice robotic surgeons. This tutoring system is meant to serve as a bridge between two stages of traditional robotic training today (e.g., computer didactics to hands-on lab). The purpose of this paper was threefold – (1) explain the process used to obtain the critical data behind a basic robotic task, (2) develop an entry level ITS to train the cognitive process and procedural steps behind multiple fundamental robotic surgery skills, and (3) provide future novice ITS developers lessons learned and future recommendations beyond the initial ITS prototype. To create this rudimentary tutoring system, cloud-based authoring system was used (i.e., GIFT) and content data was collected via a novel task analysis (Cannon-Bowers MMTA). We believe that the process of obtaining the task analysis data could be used for future ITS developers that seek to train a procedural and/or psychomotor task and that GIFT is an optimal authoring tool for novice ITS developers.

REFERENCES

Almurshidi, S. H., & Naser, S. S. A. (2017a). Design and development of diabetes intelligent tutoring system. *European Academic Research*, 9(4), 8117-8119.

Almurshidi, S. H., & Naser, S. S. A. (2017b). Stomach disease intelligent tutoring system. *International Journal of Advanced Research and Development*, 2(1), 26-30.

Anderson, J. R., Fincham, J. M., & Douglass, S. (1997). The role of examples and rules in the acquisition of a cognitive skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*(4), 932.

Azevedo,R.,& Lajoie,S. (1998). The cognitive basis for the design of a mammography interpretation tutor. *International Journal of Artificial Intelligence in Education*,9, 32-44.

Branch RM. (2010). *Instructional Design: The ADDIE Approach*. New York, NY: Springer.

Cannon-Bowers, J., Bowers, C., Stout, R., Ricci, K., & Hildabrand, A. (2013). Using cognitive task analysis to develop simulation-based training for medical tasks. *Military Medicine*, 178(10S), 15-21.

Chou, B., & Handa, V. L. (2006). Simulators and virtual reality in surgical education. *Obstetrics and Gynecology Clinics of North America*, *33*(2), 283-296.

Clancey, W. J. (1986). From GUIDON to NEOMYCIN and HERACLES in twenty short lessons: ONR final report. 1979-1985. *AI Magazine*, 7(3), 40–63.

Crowley, R. S., Legowski, E., Medvedeva, O., Tseytlin, E., Roh, E., & Jukic, D. (2007). Evaluation of an intelligent tutoring system in pathology: Effects of external representation on performance gains, metacognition, and acceptance. *Journal of the American Medical Informatics Association*, *14*(2), 182-190.

Fletcher, J. D., & Sottilare, R. (2013). Shared mental models of cognition for intelligent tutoring of teams. *Design Recommendations for Intelligent Tutoring Systems*, *1*, 239-254.

Graber, M.L., Franklin, N., & Gordon, R. (2005). Diagnostic error in internal medicine. *Archives of International Medicine*, 165, 13, 1493-1499

Intuitive Surgical. (2016). Q4 2016 Investor Presentation. Available at: http://phx.corporate-ir.net/phoenix.zhtml?c=122359&p=irol-IRHome

Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of intelligent tutoring systems. *Review of Educational Research*. 86(1), 42-78.

Martens, A., Bernauer, J., Illmann, T., & Setz, A. (2001). Docs'n Drugs- The vrtual polyclinic: An intelligent tutoring system for web-based and case-oriented training in medicine. *AMIA*,1067,433-437.

Satava, R. M. (1993). Virtual reality surgical simulator. *Surgical endoscopy*, *7*(3), 203-205.

Sharples, M., Jeffery, N. P., du Boulay, B., Teather, B. A., Teather, D., & du Boulay, G. H. (2000). Structured computer-based training in the interpretation of neuroradiological images. *International Journal of Medical Informatics*, *60*(3), 263-280.

Skinner, A., Diller, D., Cannon-Bowers, J., Smith, R., Tanaka, A., Julian, D., Kumar, R., & Perez, R. (2018). Multi-modal analysis of robot-assisted surgical training tasks. *International Journal of STEM Education*, 5:14. https://doi.org/10.1186/s40594-018-0108-5

Sottilare, R. A., Graesser, A., Hu, X., & Holden, H.. (2013). *Design recommendations for intelligent tutoring systems: Volume 1-learner modeling* (Vol. 1). Orlando, FL: US Army Research Lab.

Sottilare, R., Ragusa, C., Hoffman, M., & Goldberg, B. (2013, December). Characterizing an adaptive tutoring learning effect chain for individual and team tutoring. In *Proceedings of the Interservice/Industry Training Simulation & Education Conference, Orlando, Florida*.

Smith, R., Patel, V. R., Chauhan, S., & Satava, R. (2013). Fundamentals of robotic surgery: outcomes measures and curriculum development . *NextMed/ MMVR*, San Diego, CA.

Voytovich, A. E., Rippey, R. M., & Suffredini, A. (1985). Premature conclusions in diagnostic reasoning. *Journal of medical education*, *60*(4), 302-307.

Yudelson, M.V., Medvedeva,O.P., & Crowley,R.S.(2008) . Multifactor approach to student model evaluation in a complex cognitive domain. *User Modelling and User-Adapted Interaction*, 18(4), 315-382.