Using Cognitive Task Analysis to Facilitate Collaboration in Development of Simulator to Accelerate Surgical Training

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1. Introduction

Technological advances over the last 10 years have opened up a new venue for surgical teaching. The introduction of simulators and virtual reality provide a place to gain surgical experience without putting patients at risk.[1] We have accepted this great advantage and simply inserted simulators wherever possible into our current training experience. As simulation is put into place and tested, we realize we should also improve the method with which we learn.[2] The traditional Halsteadian method of teaching surgery was based on an apprenticeship model because there was no viable alternative to learning on the human. Hand-in-hand with this limitation was the necessity for experts to be the teachers and for the teaching moments to be moved along by the progress of the case in the operating room without the option of re-doing an error or stopping at a critical moment to ask questions. As a new generation of surgical simulators is being developed, teams around the world are realizing that there are multiple problems, which arise when new technology is simply inserted into surgical training. An expert surgeon is often not able to articulate his expertise or why he makes certain surgical decisions. However, cognitive theory tells us that learners need to be taught decision making strategies to gain expertise.[3] With simulation there is no risk to the patient or time constraints on teaching so comprehensive learning objectives from cognitive theory can be addressed. At the same time, simulators have introduced new obstacles. We are able, in a surgical simulation, to represent multiple information sources to the learner. Text, audio and moving images are imbedded into the simulator, often resulting in cognitive overload to the learner and impeding knowledge transfer.

Current simulators are built by watching experts perform surgery and by asking them to describe what they are doing. Research shows that expert knowledge is highly automated and is not easily accessible to the expert. An expert surgeon has difficulty articulating exactly what leads him to make a surgical decision. He may make errors 30-50% of the time when attempting to describe how his automated knowledge operates in practice. Not only has this been a problem in transfer of expertise to novice surgeons in the operating room, but these errors are not being addressed when simulators are designed. This problem with our current apprenticeship model of teaching is being replicated in new technology.

The next problem encountered in the first generation of surgical simulators is cognitive overload. Simulators, whether utilizing multi-media or sophisticated virtual reality, are capable of presenting information in animation, video, text, narrative, graphics, etc. The learner's attention is split among these media and it requires more mental work to integrate the information from many of these different sources. The goal when using technology needs to be a lowering of the cognitive load focusing attention only on essential, goal-relevant information. Examples of cognitive principles necessary in the development of simulators are: utilization of narrative in media displays rather than text (Narration principle) or elimination of extraneous words, sounds (e.g. music) and pictures (Coherence principle). The use of an educational expert helps developers focus on these principles to reduce the cognitive load on the learner.

In this project we use Cognitive Task Analysis (CTA), as an accepted method of teaching expertise.[4-6] We apply CTA to flexor tendon repair, a common hand surgery with long-term risks to the patient. The project describes a framework with which to look at a surgical procedure and develop technology that will complement the educational and cognitive goals of the user.

Educators have only recently been included in collaborative teams designing simulators; previously, we have had technology experts building technology around a task or procedure based on input from the task experts. As described, this technique can substitute technology for pedagogy with the result of actually making learning more difficult for the user. By incorporating educational principles into the next generation of surgical simulators, we will speed growth toward expertise and improve the way surgeons learn.

Our collaborative group at USC began simulator development with defined teaching objectives, allowing us to design existing technology and innovate new technology that will accomplish the goal of the surgical simulator—to facilitate learning and accelerate the acquisition of expertise.

2. Cognitive Task Analysis (CTA)

2.1 Principles of Cognitive Task Analysis

There are several methods for analyzing the cognitive processes of expertise. Cognitive task analysis (CTA) is one which has been successfully implemented and tested in many domains where the road from novice to expert can have a high cost in human lives. These include: surgery, emergency medicine, combat mission planning, fire fighting, and air traffic control. CTA is the process of deconstructing an expert's knowledge of a task and adapting it to the needs of the educational model. CTA produces a document that can then be used to highlight the educational goals. Our multidisciplinary team used this document to understand the specific needs of the user and how the simulator design can best meet the goals of surgical education.

Most surgery is described in a series of steps; a simple "how-to". CTA looks at when surgical decisions are made and, more importantly, what information or cues are used by the expert to make those decisions. Studies have shown that experts and novices show a greater difference in the inferences they draw than in their perception of the cues used to draw them. [7] It is the integration of learned knowledge with the patient- and situation-specific information that defines expertise.

2.2 Methods for performing cognitive task analysis

Cognitive task analysis begins with the selection of experts followed by several interviews to deconstruct the surgical task as described in CTA literature. Two or more top experts are interviewed and observed by a trained CTA analyst with subject matter expertise at the level of the trainees. (This novice level understanding of the task is important because experts ignore or assume information they have automated.) The goal of these interviews is to capture an optimal description of the sequence of all actions and decisions necessary to perform the surgical procedure. (See Figure 1) In the first stage, a description of the entire set of procedures in the surgical procedure to be taught is recorded. Seven to ten steps are then grouped into tasks. These tasks (or "chunks" in the education vernacular) are designed and sized to be easily assimilated into the working memory of the learner avoiding cognitive overload. Each piece of information becomes an educational goal for the simulator development team and a means of assessing progression toward expertise.

Information collected during surgical cognitive task analysis

1. What is the goal of this task?
2. What conditions or context must be present to start the task?
3. What is the reason for this task? (what process is at work, what conditions are being classified or changed);
4. What actions and decisions must be implemented to complete the task
5. What concepts, processes or principle knowledge is required to adjust this task to fit novel elements?
6. What equipment and materials are required?
7. What performance standards must be achieved? (e.g. time, accuracy)

Figure 1. Sample of questions asked during cognitive task analysis to elicit expertise.

Once the initial outline is complete, the steps and tasks are further described with goals, decisions, specifics of how to perform the task and factors that need to be weighed in making each decision including conditions (cues from the patient, indications and contraindications). The final document is edited, tested and then sequenced in the order in which tasks are performed; or, if there is no necessary sequence, easier tasks are sequenced before more complex tasks.

The CTA interviewer records the information collected from experts in a flow chart or outline format with tasks, goals, steps, advantages and disadvantages and if/then statements. (See Figure 2) The importance of novice interviewers is evident here to suggest language and levels of elaboration that will be most useful to other novice trainees. An attempt is also made to find the most efficient and simple, yet accurate, description of each task to facilitate novice learning. The draft outline is validated in review sessions by the experts and missing or incorrect sections are corrected. The approved CTA information is then formatted for discussion by the multidisciplinary team designing the simulator; this Instructional Design document is used to develop the teaching instrument as well as evaluation instruments and checklists.

The time commitment involved in performing CTA depends on the number of experts that must be interviewed, the CTA expertise of the interviewer, and the complexity (branching) in the decision steps that characterize the knowledge being captured. For trained CTA designers, the capturing of one hour of focused expertise requires about 30 hours of effort. While this stage of the process is very labor intensive, once captured, the CTA information does not have to be revised until the procedure changes. At that point, only the new steps need to be revised; the interview process does not have to be repeated.

3. Engine for Multidisciplinary Simulator Design

3.1 Applying Instructional Design

The documents developed from CTA clearly state what the teaching instrument (simulator) needs to accomplish. For example, instead of stating that the simulator needs to allow the user to extend the wound proximally or distally, this step is expanded. We want the learner to know the techniques for extending the wound, how to decide in which direction to extend the wound and how to decide which method (Bruner or mid-lateral) to use. We also want to insure that the learner is aware of indications and contraindications to each decision. An error can be made not only by wielding the scalpel incorrectly, but also by making a decision for the wrong reason. (See Figure 3) The principles of CTA elicitation and outlining of educational goals, can be extended to simple or complex surgeries to improve and aid in the development of simulators.

At USC, our answer to developing a simulator that transfers knowledge most effectively and efficiently is to separate media, multi-media, simulations and VR from the instructional design. We use CTA models as the instructional and assessment engine for new surgical simulators, virtual reality and multi-media design.

Task 13 **Decide if wound needs to be extended AND which method to use AND which direction to extend**

Goal: provide access to operative area without creating excessive scarring

Step 1: Decide if field is adequate to visualize and/or repair tendon

Does laceration allows visualization of 10 mm of each tendon edge?

IF YES, THEN proceed with repair

IF NO, THEN extend incision to expose an area where 10 mm of each cut edge can be brought into wound for repair

Step 2: Decide which direction to extend wound by determining likely location of cut tendon edges given mechanism of injury

Step 2A: Decide location of cut tendon edges

IF digits were in flexion during injury, THEN the distal cut edge will be distal to the injury AND the proximal cut edge will be close to the site of injury.

IF digits were in extension during injury, THEN the distal cut edge will be close to the site of injury AND the proximal cut edge will be proximal to the site of injury.

IF digits were in neutral during injury, THEN both cut edges will be close to the site of injury

Step 2B: Decide which direction to extend wound

IF the cut edge is likely distal to site of injury, THEN extend the incision AND in continuity with most lateral edge of wound.

IF the cut edge is likely proximal to site of injury, THEN extend the incision proximally AND in continuity with the most lateral edge of wound

Step 3: Decide between Bruner and mid-lateral incision, or a combination to extend incision

Goal: incorporate existing wound into extension to provide area for tendon visualization/repair

A. Bruner's incision: diagonal incision extending across one phalanx

Advantage: can easily extend proximally into the palm, provides excellent exposure of flexor sheath as well as digital nerves

Disadvantage: minimal if you don't violate tendon sheath, additional sutures

B. Mid-lateral incision: an incision along the mid-lateral line defined by depth of joint crease with digit in complete flexion

Advantage: leaves scar on the nontactile area of the finger, less visible scar because it is in area of no tension.

Disadvantage: increase risk of injury to dorsal branch of digital nerve, technically more difficult for exposure, transection of feeding vessel to vincula when elevating neurovascular bundle with skin flap.

Figure 2. Excerpt of cognitive task analysis for flexor tendon repair. Task 13 involves decisions surrounding extension of wound for exploration and tendon localization.

3.2 Methods for Collaboration

Our collaboration began by assembling a group of field experts from education, medicine, engineering, computer science and interactive media who were willing to accept the groups overriding goal as effective education of the novice surgeon. We started with one task in the instructional design format and went through each step discussing how best to teach the cognitive or technical principle utilizing technology: that which is available and that which we want to create. Through a series of these collaborative meetings with specific objectives, we were able to storyboard how the surgical procedure will be simulated utilizing the most appropriate technology to the educational goals. Our discussions focused on how each collaborator sees the simulator best meeting the educational goal. The simulator is designed to do more that simply recreate anatomy. The goals of the surgical simulation include teaching decision points and ensuring the learner knows what surgical options are available and can justify his surgical path, as well as assessing when the learner needs more guidance. As our technology experts talked through possibilities such as mentor figures, the educator described the advantages and disadvantages of visual versus aural input from a mentor figure. Each issue or possibility was discussed in this manner with the ultimate decision for how to simulate each task based on what the technology can do and what will help the learner.

Task	**Description**	**What is Skill We want to Teach?**	**What is Skill/Error We Want to Test?**	**What are decision points we Want to Teach?**	**What are Errors in Decision Making we Want to Test?**
Task 13 Step 1	Extend wound; is field adequate for visualization?	wound exploration; assessment of working space	acceptance of insufficient tendon length	decision to extend wound	failure to extend wound when visualization is inadequate
Task 13 Step 2	Extend Wound; where to extend wound			Decide where tendon is based on mechanism of disease	extending incision in wrong direction; less likely to encounter tendon
Task 13 Step 3	Extend Wound; decide method for wound extension	Correct performance of Bruner and mid-lateral incision	Insufficient knowledge of anatomic landmarks	decide method for wound extension	failure to incorporate wound into incision; compromising blood supply
		Care of neurovascular bundle	Mid-lateral incision too palmar		failure to articulate pros and cons of each method

Figure 3. Instructional Design document. Excerpt of working document elaborated from cognitive task analysis document (Figure 2). Each step has defined goals for teaching as well as actions that constitute an error by the simulator.

Using the CTA document as a guide, an instructional design document can be easily elaborated that highlights what cognitive or technical step needs to be taught and what errors need to be measured.

4 Discussion

Using CTA, our group was able to successfully design a simulator that meets the research goals of each discipline as well as the goals for surgical learning. Our methods can be used as a template and applied to any surgical procedure in the multidisciplinary development of surgical training simulators.

Given the different working styles and professional cultures of the disciplines involved in designing surgical technology a roadmap to define common goals is necessary. With the incorporation of educators into this multidisciplinary process, we were able to produce a document and a systematic approach to facilitate project development for a surgical simulator designed to meet the educational goals of the user.

Surgical simulators will not replace the expert teacher in the OR, the human body is too variable and there is still much to be learned from the expert surgeon and the subtle nuances of each case. But each new generation of simulators should be able to teach more expertise outside the operating room where real patients are at risk. Surgical simulator design needs to be wrapped around sound educational goals that will accelerate the acquisition of expertise by paying attention to possible stumbling blocks like cognitive load and expert error in articulating expertise. What we can do by designing simulators around cognitive task analysis is to progress the learner along his learning curve on the virtual patient where errors have no consequence. This will, in turn, better prepare the novice surgeon for refinement of skills with the expert in the operating room.

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