THE USE OF COGNITIVE TASK ANALYSIS TO IMPROVE ANESTHEIA SKILLS TRAINING FOR POSTOPERATIVE EXTUBATION

Kären K Embrey CRNA, Ed.D
Assistant Professor of Clinical Anesthesiology; Assistant Director for Clinical Services, Program of Nurse Anesthesia, Keck School of Medicine, University of Southern California, Los Angeles, CA.
Kenneth Yates Ed.D
Associate Professor of Clinical Education; Director for Program Evaluation, Rossier School of Education, University of Southern California, Los Angeles, CA.

Keywords: *Cognitive task analysis, extubation training, expertise and anesthesiology*

Abstract

This study examines knowledge gains in 25 nurse anesthesia trainees, following the implementation of a novel instructional design, which incorporated cognitive task analysis (CTA) to teach an adult postoperative extubation procedure. CTA is a knowledge elicitation technique employed for acquiring expertise from domain specialists to support the effective instruction of novices. Instruction guided through CTA is effective in improving surgical skills training for medical students and surgical residents. The standard, current method of teaching clinical skills to novices in nurse anesthesia practice relies on recall-based instruction from domain experts. However, this method is limited by the constraints of expertise, including automation of procedural knowledge by the expert practitioner. Automated knowledge escapes conscious awareness and access, thus impeding clear explication of comprehensive essentials for task execution during instruction. CTA guided instruction has been shown to maximize conceptual, declarative and procedural knowledge gains in novice practitioners by clearly explicating the essentials employed when experts execute tasks. Knowledge gains for the task of postoperative extubation in 13 junior and senior nurse anesthesia trainees were compared to those of 12 trainees, receiving standard instruction. The study results indicate that CTA-based instruction has a positive and significant effect on procedural knowledge gains in the novice anesthetist.

Video: Cognitive Task Analysis

Introduction

"There are things that we know but cannot tell. This is strikingly true for our knowledge of skills."[1] Healthcare education must incorporate processes to ensure optimal patient outcomes as well as best practices for trainee education.[2] This is especially important for complex cognitive tasks or skills such as postoperative tracheal extubation. This task is strategically performed to facilitate resumption of respiration, via the normal anatomical airway once mechanical assistance or an artificial airway is unnecessary for effective postoperative patient ventilation.[2] The training of novice practitioners for the performance of this critical skill must include both the conceptual knowledge (what to do and why to do it) and procedural knowledge (when and how to do it). Skills training however, may present unique pedagogical challenges to the expert charged with educating novices, owing to the limitations of automated or implicit knowledge which is not readily accessible or shared by expert practitioners.[3] Seminal research in the acquisition and development of expertise suggests that the development of expertise occurs roughly over 10,000 hours of deliberate practice in a specific domain, where performance feedback and improvement are continuous.[4,5] However over time, knowledge in the expert practitioner becomes unconscious or implicit and automated.[6] Moreover, research in educational psychology suggests that experts routinely omit up to 70% of essential information for task execution when they rely on recall during clinical instruction.[7,8,9] Such omissions in clinical instruction may be counteracted by the use of cognitive task analysis (CTA) methods. Cognitive task analyses are methods used to elicit the full spectrum of expertise necessary for complex skill execution in order to improve instructional design for the teaching of these skills. In the training of novice anesthesia practitioners, the standard current method of teaching clinical skills such as postoperative extubation relies heavily on recall-based instruction from domain experts, either in the operating room, during case management, or in the simulation laboratory.

Complex cognitive tasks such as those necessary in the performance of postoperative extubation integrate both controlled, conscious (conceptual) and unconscious or automated (procedural) knowledge. This knowledge must be strategically executed to achieve optimal task outcomes during task execution.[10] While experts may perform complex tasks and execute procedures with exceptional ease and efficacy, they often omit the details of just how they perform these tasks because they don't consciously access or share automated aspects of the task. Advances in cognitive science however may offer a solution to the problem of procedural and declarative knowledge transfer from experts to novices, through the application of CTA methods. Cognitive task analysis is a systematic approach for capturing the full spectrum of knowledge that experts employ during the execution of complex tasks. This method of expertise elicitation explicates both the observable actions and the cognitive processes (decisions, judgments, and analyses) experts use to solve difficult problems and perform complex tasks.[11] There are five steps to conducting CTA.[12] First, the knowledge analyst becomes familiar with the domain and tasks to be captured. Then, each type of knowledge within the task and sub-tasks is identified. In the third step, the analyst conducts a semi-structured interview to capture the conceptual knowledge related to the task, as well as the action and decision steps the expert uses to perform the task. Next, the information collected is analyzed and verified by the expert. Finally, the results are formatted for the intended use, such as a protocol for performing the task, job aids, and checklists. When CTA is conducted with multiple experts, often the 70% rule of information omissions can be reversed.[13,14] When incorporated into training, the application of CTA elicited expertise may offer an improvement over conventional clinical instruction methods that primarily rely on expert recall,[9] by delineating task rules and formulating highly accurate and exhaustive algorithmic descriptions of challenging cognitive tasks.[15] The application of CTA techniques has proven successful in improving learner outcomes in medical and surgical skills training[16,9] as well as improving direct patient outcomes following surgical skills training.[17]

The purpose of the current study was to determine if CTA based instruction of postoperative tracheal extubation is more effective than conventional clinical instruction provided to anesthesia trainees, as measured by conceptual and procedural pre and posttests aimed at assessing both explicit (conscious) and implicit (unconscious) knowledge. The study compared the comprehensive knowledge gains of students receiving postoperative extubation training following either standard recall-based instruction or an experimental instructional design using a CTA technique. The following questions were explored:

1. Do participants in the experimental group demonstrate greater conceptual knowledge (what to do and why to do it) on postoperative tracheal extubation than participants in the control group?
2. Do participants in the experimental group demonstrate greater procedural knowledge (when and how to do it) in performing postoperative tracheal extubation than participants in the control group?

The second question further examined measures on task accuracy, timing for task completion and the correct sequencing of subtasks within the main task of postoperative tracheal extubation.

Materials and Method

This randomized experimental study employed a design based on content captured by the use of a cognitive task analysis to elicit knowledge from anesthesia experts for the task of adult, awake postoperative extubation. The CTA elicited expertise was then used to develop the experimental instructional curriculum and the assessment tool used in the quantitative assessments of instructional outcomes. The CTA procedure for knowledge elicitation followed the five steps outlined in Clark et al [15] Three anesthesia experts were individually interviewed to elicit knowledge about the action and decision steps, indications and contraindications, standards, and equipment for the awake adult postoperative tracheal extubation task. The experts were also asked about how to manage difficult or unexpected occurrences during extubation as well as the conditions under which they would defer extubation. Additional information regarding other sensory cues and input during task and subtask execution was also gathered and included sounds, smells, and tactile input surrounding task execution. During a verification process, the interviewees subsequently reviewed and clarified the coded data obtained in the interviews and represented by a written protocol for performing the procedure. Individual protocols from the three experts were then aggregated to generate a "gold standard" protocol for extubation that was reviewed by three other anesthesia experts. The resulting cumulative data were employed to generate the instructional protocol and assessment materials, including an algorithmic instructional outline explicating exhaustive IF…THEN scenarios which could arise during awake adult postoperative extubation and a checklist for evaluating the post instructional performances of trainees.

Following institutional review board approval and informed consent, 25 student registered nurse anesthetist volunteers were randomized to stratified control or experimental instructional groups. The volunteers included 14 junior students (novices) in their first semester of training, who had not previously performed tracheal extubation, and 11 senior students (intermediates), who had each previously performed roughly 100 supervised extubations. The experimental group of students (7 juniors, 6 seniors) received instruction employing the CTA guided curriculum, during a demonstrated task execution, while the control group (7 juniors, 5 seniors) received conventional recall-based instruction during a demonstrated task execution. Except for the CTA-derived content for the experimental group training, the instructional design, development, and implementation were identical for both groups.

Instruction on tracheal extubation for both the experimental and control groups was conducted in a state-of-the-art, high fidelity, simulation laboratory using the METIman® (CAE Healthcare) human patient simulator, which reacts to interventions in real time with dynamic and nuanced, high fidelity human physiological responses. Experimental participants were instructed using the CTA guided curriculum generated in the pre-study period. Instruction was delivered during a simulated patient extubation with the instructor following the CTA generated protocol. Controls received the standard recall-based instruction for postoperative tracheal extubation, which included standard recall-based instruction on the task during a simulated patient extubation. Instruction and evaluations of both the control and experimental groups of trainees were videotaped for analysis and data coding. Task instructors, both senior faculty members, shared similar experience with clinical instruction in the domain of nurse anesthesia practice and had similar expertise in the use of the simulation laboratory. Both instructors employed a think aloud method of communication during instruction. All study participants underwent uniform pre-briefing and debriefing sessions in keeping with the simulation center's policies for lab participation and training and testing content confidentiality. Students' declarative knowledge was assessed both before and after the training intervention via written exam. Both the pre and posttest incorporated a case based patient scenario for adult, awake extubation and included questions such as the following to assess declarative knowledge: 1) Name 6 pieces of equipment necessary for safe postoperative extubation, 2) What are 4 indications that your patient is ventilating effectively on her own once the ventilator has been turned off, 3) Put the following 6 subtasks into the correct order for the safest postoperative extubation: a) suction the oropharynx, b) remove the patient's protective eye tape, c) take the patient off of the ventilator to evaluate how well she is able to breathe on her own, d) reverse the neuromuscular blocking agent, e) evaluate the train of four response, f) place an oral airway. A total of 10 such questions were included on the written pre and posttest. Procedural knowledge was assessed by 2 trained observers using the CTA based checklist during participant task execution in the simulation laboratory following instruction though conventional or experimental method. The checklist was used to assess the execution of the extubation sequence and the subtasks within the 4 delineated temporal categories as seen below in Figure 1. The checklist developed for this purpose was the simplest outline of the necessary steps for a safe extubation. The exhaustive algorithm for extubation which was developed from the CTA interviews with anesthesia experts could be used to generate expanded content and checklists for future task training by evaluating any number of IF…THEN situations that might arise during an extubation sequence. More advanced checklists could be used to assess additional conceptual knowledge or strategic decision making during the process of extubation such as in the management of deep extubation or extubation for the patient with suspected airway edema. The simple extubation sequence checklist used for this experiment included content reflecting decision making strategies such as: IF the surgeons have completed the surgery but the train of four monitor indicates that the patient has 0/4 twitches THEN begin tapering the inhalation agent but keep the patient asleep until the train of four monitor indicates neuromuscular blocking agents can be antagonized. The temporal categories for the subtasks of the simplified checklist for postoperative awake extubation included 1) begin tapering anesthetics in response to cues from surgeons, 2) position patient for safe emergence and extubation (ensure patient is not in Trendelenberg, lithotomy or other unfavorable position), 3) emerge the patient and extubate the trachea, and 4) monitor and confirm post extubation respiratory homeostasis. The students' performances were assessed by 2 trained observers to evaluate whether they did or did not perform each of the subtasks in these temporal categories, and whether their performances were executed correctly or not. For transparency of decision making, student participants employed a think aloud method of communication during task execution.

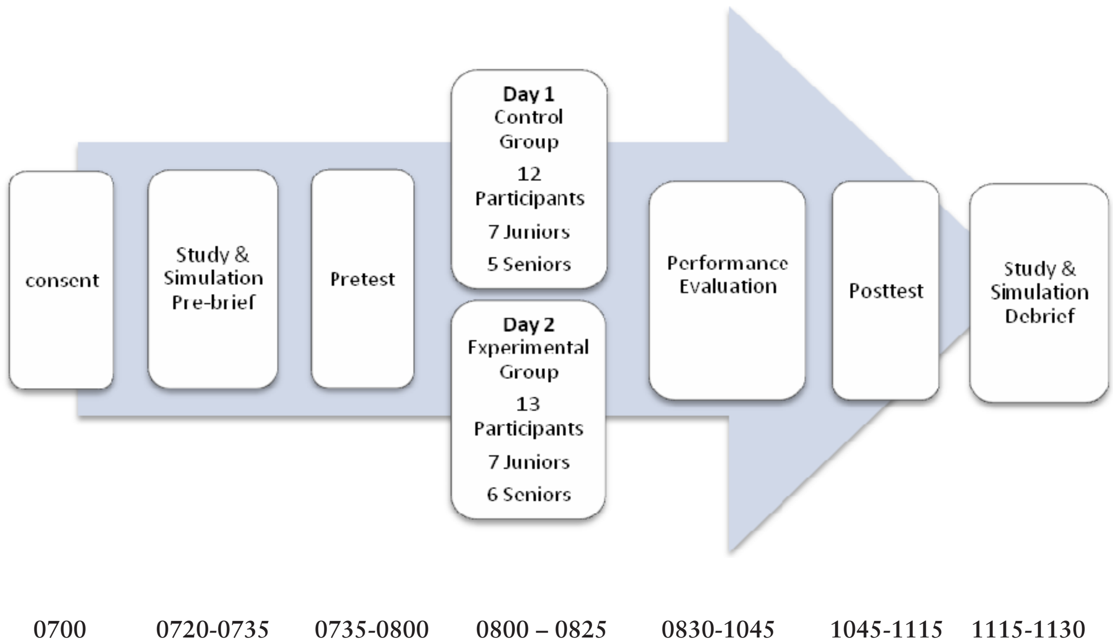
Figure1. Procedural Checklist for Adult, Awake Postoperative Extubation

Temporal Frame and Sub Task for Adult Awake Extubation	Circle if not done (ND) Or if done incorrectly (DI)	Place check mark if done correctly	Comments
1. Begins tapering anesthesia in response to cues from surgeons			
a) Checks train of four response	ND DI		
b) Administers neuromuscular block reversal	ND DI		
c) Suctions oropharynx	ND DI		
d) Monitors for spontaneous ventilation	ND DI		
2. Positions patient for safe emergence; extubation			
a) Employs universal precautions	ND DI		
b) Places oral airway	ND DI		
c) Returns patient to head of bed; supine	ND DI		
d) Ensures patient is safely restrained	ND DI		
e) Removes eye tape	ND DI		
f) Turns O_2 to 100%	ND DI		
g) Monitors alveolar concentration of gases	ND DI		

3. Emerges the patient and extubates the trachea a) Assesses the patient for emergence; observes for return of reflexes b) Does not extubate when patient remains in Stage II c) Check respiratory rate is 8- 30/ min, checks tidal volume (TV) is appropriate (5cc/kg); $ETCO_2$ < 45cmH_2O d) Assists ventilation by hand when spontaneous ventilation is inadequate e) Reassesses respiratory status for rate and minute ventilation. Rate 8- 30/min, TV appropriate &$ETCO_2$ < 45cmH_2O f) Looks for regularity of respiratory rate g) Confirms patient is in Stage I using specific criteria (such as eye opening, hand squeeze, head lift, tongue projection)_ h) Places circuit mask, syringe & suction in appropriate reach i) Loosens tape on face j) Deflates endotracheal tube (ETT) cuff k) Increases positive pressure ventilation; squeezes bag or sets APL valve to 20cmH_2O pressure and removes ETT from trachea	ND DI ND DI ND DI ND DI ND DI ND DI ND DI ND DI ND DI ND DI ND DI		
4. Monitor and confirm post extubation respiratory homeostasis a) Immediately following extubation places the circuit mask on the patient's face and confirms CO_2/ mist (pt is free of obstruction) b) If not, repositions the mask / checks for breath holding/ provides chin lift c) If obstruction is suspected places OA(uses tongue blade or NA as needed) d) Suctions again post extubation if needed e) Confirms respiratory homeostasis & places pt on transport mask at > 6LPM f) Raises the head of the bed, keeps O_2 saturation monitor in place until leaving the OR g) Monitors patient during transport to PACU – watches for mist in the mask/ chest rise/ skin color and listen for obstruction	ND DI ND DI ND DI ND DI ND DI ND DI ND DI		

Figure 2 below shows the timeline for the study which was conducted over two days.

Figure 2. Study Flow and Timeline



Results

The purpose of this study was to determine if CTA based instruction of postoperative tracheal extubation is more effective than conventional clinical instruction by domain expert provided to anesthesia trainees, as measured by conceptual and procedural pre and posttests. For all statistical analyses in this study a 95% confidence level ($p < 0.05$) was employed. Using independent *t*-tests, comparisons were made of the differences between the control and experimental groups' performances for both declarative and procedural knowledge. The study also evaluated the expected and observed performances of students in both control and experimental groups who had prior experience performing extubation and compared these to those of students without prior experience performing the task. To examine effects of prior knowledge on procedural performance for correct subtask sequencing, X^2 values were calculated using the raw data from the assessments of the experimental senior and junior students and the control senior and junior students. These X^2 values were then tested for significance.

Question 1: Do participants in the experimental group demonstrate greater conceptual knowledge (what to do and why) on postoperative tracheal extubation than participants in the control group? In the assessment of declarative knowledge, an independent samples *t*-test demonstrated no significant differences in baseline or post intervention declarative knowledge on extubation between the control and experimental groups: t (23) = -.843 (p= .408), thus demonstrating equivalence in conceptual knowledge prior to the training, and no significant gain by the experimental group on conceptual knowledge during the training.

Question 2: Do participants in the experimental group demonstrate greater procedural knowledge (when and how to do it) in performing postoperative tracheal extubation than participants in the control group? For this question, task accuracy represented the measure of procedural knowledge. Findings demonstrated a significant difference for juniors who received CTA guided instruction (70.46 ±12.43), compared to the control group of juniors (60.71 ± 6.99) (p =.047) who received standard recall-based instruction. There was also a trend toward improvement in task accuracy in the experimental senior students' performances compared to control senior performances, though this was not a statistically significant finding.

The second research question further examined measures on task expediency by examining the time required to complete the task, and the correct sequencing of subtasks within the main task of postoperative tracheal extubation. Subtasks included measures such as suctioning the oropharynx, antagonizing the neuromuscular blocking agents and assessing for adequate patient ventilation. For task expediency, a significant level of expediency was found (8.83 minutes ± 1.33) for the experimental group of seniors and juniors when compared to their control counterparts

(10.75 minutes ± 2.34) ($p = .022$). Juniors in the experimental group outperformed control juniors; (9.00 minutes ± 1.291) versus (11.43 minutes ± 2.637) ($p = .049$) in task expediency.

A comparison between the performances of all junior and all senior students in the study for the execution of correct subtask sequencing of the extubation skill set was performed. The findings were significant $X^2(1, N = 25) = 8.766$, $p = .003$, and not unexpected as all senior students had performed roughly 100 extubations before the study. However, the difference in expected and observed performance was particularly statistically significant for the senior experimental students ($X^2 = 6.198$, $p = .013$). These results may demonstrate that CTA guided instruction is effective in improving procedural knowledge gains even in the learner with higher levels of prior experience, in whom the task may already be automated to some extent. Under conditions of prior experience and task automation, instructors face the challenge of students with prior beliefs and methods which must be "unlearned" to facilitate effective instruction. The CTA guided instructional format appeared to effectively meet this challenge.

In summary, junior students, task novices demonstrated significant improvements on task accuracy as well as task expediency following CTA guided instruction on adult, awake postoperative tracheal extubation. These findings support the benefits of CTA guided instruction for novice practitioners. Interestingly, more experienced seniors in the experimental group also demonstrated a trend toward improvements in task accuracy and expediency when compared to control group seniors. Experimental senior students also demonstrated statistically significant improvements in correct sequencing for the subtasks of extubation, despite the burden of their prior knowledge which had to be unlearned. This important finding may demonstrate the added benefit of CTA guided instruction for students or practitioners with higher levels of prior knowledge, in whom it can be assumed, task automation is already established to some degree.

Table 1: Percent Task Accuracy Following Instruction

Table 2: Task Expediency Following Instruction

Table3: Correct Subtask Sequencing Following Instruction

Discussion

The purpose of this study was to examine the effectiveness of CTA guided instruction compared to conventional recall-based clinical instruction delivered to student registered nurse anesthetists for adult, awake postoperative tracheal extubation. The standard, current method of teaching clinical skills in the operating room or simulation lab to novices in medical and nursing specialties, including anesthesiology, relies on recall-based instruction from domain experts. Instruction by experts however is limited by task automation on the part of the expert practitioner. Automated or unconscious knowledge is not readily accessible to the expert teacher and may inhibit explication of all the necessary subtasks and essentials for task execution during teaching. Cognitive task analysis or CTA is a comprehensive knowledge elicitation technique used for acquiring expertise and designing exhaustive protocols from information gained from domain specialists which can support the effective instruction of novices. The application of CTA guided instruction has been demonstrated as successful in improving learner outcomes in medical and surgical skills training[16,9] as well as improving direct patient outcomes following surgical skills training.[17]

Findings from the current study demonstrate positive trends and statistically significant improvements in the performances of student registered nurse anesthetists learning the task of adult, awake postoperative tracheal extubation through CTA guided instruction in the simulation laboratory, when compared to controls receiving conventional recall-based instruction.

This is the first known study employing CTA to inform instructional content for nurse anesthesia task training, and the study's findings are positive and in keeping with other similar studies examining surgical skills training for residents and medical students. Performance improvements in the anesthesia trainees were specifically significant for procedural knowledge gains in the areas of task accuracy, task expediency and subtask sequencing following CTA-guided instruction. Similar studies with larger participant pools may be required to more thoroughly evaluate the efficacy of CTA-guided instruction for skill acquisition in nurse anesthesia training.

References

1. Polanyi M. *Personal Knowledge*. Chicago, IL: University of Chicago Press; 1962.
2. Embrey KK. *The Use of Cognitive Task Analysis to Capture Expertise for Tracheal Extubation Training in Anesthesiology* [dissertation]. Los Angeles, CA: University of Southern California; 2012. http://gradworks.umi.com/3513751.pdf. Accessed September 22, 2013.
3. Chi MT. Two approaches to the study of experts' characteristics. In: Ericsson KA, Charness N, Feltovich PJ, Hoffman RR, eds. *The Cambridge Handbook of Expertise and Expert Performance*. New York: Cambridge University Press; 2006:21–30.
4. Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev*. 1993;100(3):363-406.
5. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med*. 2004;79(10):S70-S81.
6. Clark RE. Yin and yang: cognitive motivational processes operating in multimedia learning environments. In: van Merrienboer JJ, ed. *Cognition and Multimedia Design*. Herleen, Netherlands: Open University Press;1999.

7 Feldon DF, Clark RE. Instructional implications of cognitive task analysis as a method for improving the accuracy of experts' self-report. In: Clarebout G, Elen J, eds. *Avoiding Simplicity, Confronting Complexity: Advances in Studying and Designing (Computer- based) Powerful Learning Environments*. Rotterdam, Netherlands: Sense Publishers; 2006:109-116.

8 Pugh CM, Santacaterina S, Da Rosa D, Clark RE. Intraoperative decision making: more than meets the eye. *J Biomed Informatics*. 2011;3:486-496.

9 Yates KA, Sullivan ME, Clark RE. Integrated studies in the use of cognitive task analysis to capture surgical expertise for central venous catheter placement and open cricothyrotomy. In: *Symposium of the Association for Surgical Education*. Boston, MA; 2011.

10 van Merriënboer JJG, Clark RE, de Croock MM. Blueprints for complex learning: the 4C/ID-model. *Ed Technol Res Dev*. 2002;50(2):39-61. doi: 10.1007/BG02504993.

11 Schraagen JM, Chipman SF, Shalin VL. *Cognitive Task Analysis*. Mahwah, NJ: Lawrence Erlbaum Associates; 2000.

12 Clark RE, Feldon D, van Merriënboer JJG, Yates KA, Early S. Cognitive task analysis. In: Spector JM, Merrill MD, van Merriënboer JJG, Driscoll MP, eds. *Handbook of Research on Educational Communications and Technology*. 3rd ed. Mahwah, NJ: Lawrence Erlbaum Associates; 2008:578-591.

13 Crispen PD. *Identifying the Point of Diminishing Marginal Utility for Cognitive Task Analysis Surgical Subject Matter Interviews* [dissertation]. Los Angeles, CA: University of Southern California; 2010. http://usc.summon.serialssolutions.com. Accessed September 20, 2013.

14 Chao CJ, Salvendy G. Percentage of procedural knowledge acquired as a function of the number of experts from whom knowledge is acquired for diagnosis, debugging and interpretation tasks. *Int J Hum Compu Interact*.1994;6:221–223. doi:10.1080/10447319409526093.

15 Clark RE, Pugh CM, Yates KA, Sullivan ME. The use of cognitive task analysis and simulators for after action review of medical events in Iraq. In: *Technical Report Produced under Contract W81XWH-04-C-0093 from the U.S Army Medical Research and Materiel Command*. Fort Detrick, MD; 2006.

16 Sullivan ME, Ortega A, Wasserberg N, et al. Assessing the teaching of procedural skills: can cognitive task analysis add to our traditional teaching methods? *Am J Surg*. 2008;19:20–23. doi:10.1016/j.amjsurg.2007.08.051.

17 Velmahos GC, Toutouzas KG, Sillin LF, et al. Cognitive task analysis for teaching skills in an inanimate surgical skills laboratory. *Am J Surg*. 2004;1:114-119.