Handbook of Research on Educational Communications and Technology

Cognitive Task Analysis for Expert-Based Instruction in Healthcare

--Manuscript Draft--

Manuscript Number:	
Full Title:	Cognitive Task Analysis for Expert-Based Instruction in Healthcare
Article Type:	Chapter
Corresponding Author:	Richard Clark, Ed.D. University of Southern California Rancho Palos Verdes, CA UNITED STATES
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	University of Southern California
Corresponding Author's Secondary Institution:	
First Author:	Richard Clark, Ed.D.
First Author Secondary Information:	
Order of Authors:	Richard Clark, Ed.D.
Order of Authors Secondary Information:	
Abstract:	This chapter presents an overview of the rationale and evidence for the use of Cognitive Task Analysis (CTA) in healthcare including: It presents a brief history and definition of CTA, the reason it is being adopted for healthcare education, evidence for its learning benefits when used in evidence-based instructional design and medical simulators, an example of how one of the evidence-based CTA methods was implemented in healthcare and suggestions for future research. The point is made that when evidence-based CTA methods are used, learning from CTA-based healthcare instruction increases an average of 45 percent when compared with current task analysis methods.

Cognitive Task Analysis for Expert-Based Instruction in Healthcare

Richard Clark

University of Southern California, U.S.A.

Abstract:

This chapter presents an overview of the rationale and evidence for the use of Cognitive Task Analysis (CTA) in healthcare including: It presents a brief history and definition of CTA, the reason it is being adopted for healthcare education, evidence for its learning benefits when used in evidence-based instructional design and medical simulators, an example of how one of the evidence-based CTA methods was implemented in healthcare and suggestions for future research. The point is made that when evidence-based CTA methods are used, learning from CTA-based healthcare instruction increases an average of 45 percent when compared with current task analysis methods.

Keywords:

Cognitive Task Analysis, Instructional design, Training, Expertise, Decision making, Front-end analysis, Simulation.

Introduction:

Cognitive task analysis is a term that describes approximately 100 different strategies developed in many different nations for identifying; analyzing and structuring the knowledge and skills experts apply when they perform complex tasks (Schraagen, J. M., Chipman, S. F., and Shalin; Yates and Feldon, 2008). CTA is “cognitive” in the sense that it attempts to identify the mental processes and decisions that experts use to achieve a goal and/or solve a complex problem. CTA focuses on ”tasks” that people are required to perform. And CTA is an “analysis” system in that it permits the description, categorizing and organizing of the cognitive processes and decisions that are captured (Clark & Estes, 1996). This review is further limited to CTA strategies that are evidence-based; peer reviewed, designed to support instruction or simulators and are intended to be applied to healthcare education.

A Brief History of CTA

The systematic analysis of tasks has been a common feature of instructional planning for many decades. CTA has its origin in the ergonomics movement started in the late 1800's and the development of behavioral task analysis of manual labor jobs in the early 20th century in the United States by the scientific management researchers Frank and Lillian Gilbreth (Gilbreth and Gilbreth, 1919), the couple who were the subject of the book and movie "Cheaper by the Dozen". These early task analysis methods resulted in significant increases in technology, training and performance including the development of the QWERTY keyboard, a 300 percent increase in bricklaying and increases in emergency room efficiency and effectiveness[1]. Yet in the 1970's, as cognitive psychology developed, it became obvious that more was necessary. Behavioral task analysis was not able to capture work in the form of the critical and complex mental decisions and analytical strategies because they could not be directly observed. CTA was developed to add cognitive elements of work to the analysis of all expertise.

After the publication of Schneider and Shiffrin's (1977) analysis of automatic and controlled cognitive processing it became obvious that an additional barrier to capturing expertise is that it is largely automated and unconscious. Experts are largely unaware of how they decide and analyze problems in their specialty area (see for example the review by Clark and Elen, 2006). Thus CTA's was needed to help identify more of

---

[1] For a more detailed history of CTA, consult Hoffman and Militello, 2007.

the specific, operational elements of expert's cognitive processes. It also gradually became clear that while experts who teach provide nearly all healthcare instruction, they may be unaware of a majority of the critical decisions and analysis strategies their students need.

Expertise

Expertise, by its nature, is acquired as a result of continuous and deliberate practice in solving problems in a domain (Ericsson, 2004). As new knowledge is acquired and practiced, it gradually becomes automated and non-conscious. For example, once we learn how to drive, we can do so without thinking much about the actions decisions we make to navigate even difficult traffic and instead are able to talk to fellow passengers or listen to the radio. Many popular accounts of the social and cognitive utility of automated expertise have been published in the past decade (see for example Ericsson, 2004; Ericsson and Charness, 1994; Gladwell, 2005; Wegner, 2002). Automated knowledge helps overcome limits on the amount of conscious information we can hold in "working memory" and free our minds to handle novel problems. Yet it also causes experts to be unable to completely and accurately recall the decision knowledge and analytical skills that are an essential component of their expertise – event though they can solve complex problems using the knowledge they can't describe.

<u>Experts don't know what they don't know.</u> Automated expertise causes significant though unintended omissions when experts attempt to communicate their skills to others. Prior attempts to use standard interview or self-report protocols to extract the decision-making and problem solving strategies of surgical experts for use in educational settings have been problematical. Cognitive studies suggest that the resulting information often contains significant errors and omissions (Clark and Estes, 1997; Clark et. al. 2008; 2010). Glaser et al., (1985); Besnard, (2000); and Feldon, (2004) provide evidence that when experts teach, they leave out or distort approximately seventy percent of the information

needed by students to learn and apply surgical techniques. Healthcare professionals who teach do not often recognize these errors even though they wish to give accurate information to students, presumably because the knowledge they are describing is largely automated and unconscious (Wheatley & Wegner, 2001). The problem is further complicated by the fact that experienced healthcare professionals mistakenly believe that their reports are complete and accurate and that they solved the problems they are describing in a conscious, willful, deliberate manner (Wegner, 2002). These reporting errors most likely increase in number and severity under time-pressure and anxiety producing situations (Hunt & Joslyn, 2000) such as those experienced when surgeons teach and monitor students while they practice surgery in teaching hospitals.

During the past 25 years, advances in cognitive science and human performance research have resulted in the development of cognitive task analysis (CTA) as a group of knowledge analysis methods that capture the non-conscious knowledge experts use to solve complex problems and perform demanding tasks. By capturing the decisions and other analytical processes experts use in problem solving, instruction can be developed that more completely replicates expert performance. Students who receive more complete information are able to learn more quickly and perform with fewer "trial and error" learning that may put patients at risk (Clark et al, 2010). The evidence for the benefits of CTA are obvious in two recent meta analyses.

Meta-analysis of CTA studies. Meta-analytic reviews of research on instructional studies where CTA is used as part of the design of instruction provide strong evidence for its benefits. Lee (2004) analyzed 38 comparison studies and reported an overall average post-training learning and performance gain of about 46 percent (Cohen's d = 1.72) for CTA training when compared to more traditional training design using expert-based task analysis. In a more recent and more conservative meta-analysis, Tofel-Gehl (In preparation) analyzed 57 comparison studies and reported an overall learning gain of 31 percent (Hedges g = .88) from all studies. She also reported different effect sizes for different CTA methods ranging from a low of 13 percent gain (g = .33) for the popular Critical Decision Method (Klein, Calderwood and Macgregor, 1989) to a high of 45 percent gain (Hedges g = 1.598) for CTA methods based on the PARI (Precursor, Action, and Interpretation) type methods (Hall, Gott, and Pokorny, 1995; Clark, 2006). This most recent meta-analysis makes it clear that some CTA methods are much more effective when applied to instruction. Clark and Estes (1989) describe some of the more prominent CTA methods in greater depth.

In addition to learning benefits, it has been assumed that CTA based professional studies curriculums in universities would benefit graduates by making them much more attractive to employers.

Employer satisfaction with healthcare graduates. Another source of concern that has contributed to interest in CTA derives from evidence from healthcare employer surveys. In one survey, over 68 percent of healthcare employers in areas where occupational certification and licensure is required expect that job applicants will lack essential occupational skills (Workforce connections, 2011). This is higher than the average expectation of less than 53 percent for all occupations. In nursing for example, the inability to handle the intense working environment, advanced medical technology and patient needs results in new graduate nurse turnover rates of about 35 percent in rural areas to 60 percent in urban areas during the first year of employment. This results in a loss of approximately $40,000 for employer hiring and orientation expenses for each replacement (Halfer and Graf, 2008). It also contributes to the huge expense of on the job training for newly hired healthcare professionals, estimated at 68 percent of the training and education budget in healthcare. Discussions about the cause of this situation in Nursing and other healthcare professions focus on the failure of university and specialist training organizations to capture the current context, challenges and expertise required for students to perform adequately after being trained. It is possible that CTA based professional studies programs would help close some of these gaps between the demands placed on new healthcare employees and the adequacy of the training they have received. Studies in a variety of healthcare areas and tasks seem to validate the potential learning and transfer benefits of CTA based instruction.

Evidence from Applications of CTA to Healthcare Training

A number of studies conducted in the past two decades have provided enticing views of the possible benefits of CTA to various healthcare areas such as the training of nurses, surgeons, the functioning of medical teams, the design of medical simulators and other technology-based supports for healthcare professionals. Selected and briefly described examples of these studies are presented next.

Nursing. Crandall and Gretchell-Leiter (1993) described a study where a CTA of expert neonatal nurses exposed a strategy for diagnosing life-threatening infections in premature infants that was significantly more effective than the textbook method taught in universities. Registered nurses who averaged 13 years of overall experience and 8 years specializing in neonatal infants were asked to describe critical incidents in which the nurses believed they had significantly impacted an infants medical outcome. Nurses were asked to be specific about their assessment strategies, diagnostic cues, and the clinical decisions they made. The CTA analysts utilized semi-structured knowledge elicitation probes developed by CTA pioneer Gary Kline and colleagues (Klein, Calderwood and Macgregor, 1989) to identify additional relevant information that was not described during free recall. Analysis of the CTA interviews revealed that the structured questions elicited significantly more indicators of medical distress in infants suffering from sepsis. The nurses' CTA explanations of the cues they used were either not mentioned or described only vaguely during free recall. Comparison of the CTA elicited cues to those described in the medical and nursing literature provided strong evidence that the nurses' statements were not derived from their textbook knowledge. More than one-third of the individual cues (25 out of 70) used to correctly diagnose infant infections were not listed in any of the existing medical research or training literature. These cues comprised seven previously ignored categories that were subsequently incorporated into textbooks and training for nurses entering neonatal intensive care (Crandall & Gamblian, 1991).

Physicians. Velmahos et al. (2004) studied the expertise of emergency medicine specialists. In a controlled study using the CPP CTA method (Clark, 2006), half of a randomly assigned group of 24 medical students were taught a routine emergency procedure in a traditional modeling and practice strategy by expert emergency physicians. These students' post training performance was compared with the other half of the medical students who were trained with information gathered from a CTA conducted with the same emergency medicine experts who taught the control group. It was clear from the analysis that the information provided to the traditionally taught students by the experts contained significant omissions and errors, and primarily focused on essential decisions and problem solving strategies that were never discussed or were incorrectly described by the experts.

After training, whenever the medical students performed the routines with patients in the following year, they were observed and evaluated by judges who were unfamiliar with their experimental status. The experimental group who received training based on CTA outperformed the expert taught control group on all analytical (diagnostic) and many performance items by over 50 percent during the year following training. Velmahos (personal communication) also reported that the traditionally trained doctors caused four serious medical emergencies applying the medical protocol with patients (about average for new physicians) and those with CTA training made no life threatening mistakes.

Dental Hygienists. Mislevy et al (1999) applied CTA to capture the assessment, treatment planning and progress monitoring expertise of dental hygienists in order to develop a licensure test as well as a coached practice computer system where achievement testing could be performed. The resulting computer-based system for assessment and simulation of dental hygiene skills and behaviors has been successfully tested and is in use.

Surgery Residents. Campbell et al (In press) applied CPP CTA to study the relative effectiveness of CTA based instruction on performance of an open cricothyrotomy (OC) when compared with instruction provided by the same experts who participated in CTA interviews. In this study 26 second and third year surgery residents where separated into two groups. All participants completed a pretest on OC knowledge and their self-efficacy related to the procedure. One group received CTA based instruction and experts taught the control group. The CTA group significantly out-performed the control group based on a 19-point checklist score (CTA mean score: 17.75, SD = 2.34, control mean score: 15.14, SD = 2.48, p = .006). The CTA group also reported significantly higher self-efficacy scores based on a 140-point Bandura self-efficacy scale (CTA mean score: 126.10, SD = 16.90, control: 110.67, SD = 16.8, p = 0.029). This study provides evidence that CTA based instruction can not only increase learning but also increase students' confidence that they can perform complex CTA-based procedures.

The learning, self-efficacy, error reduction and assessment benefits of CTA have been established in a number of healthcare areas. Replicating these studies and extending CTA benefits to additional areas requires careful consideration of the way that analysts and experts are selected and the choice of the specific CTA protocol that is used. The discussion turns next to what has been learned about the selection of analysts and experts who participate in CTA interviews.

Selecting Analysts and Experts for Healthcare Cognitive Task Analysis

A trained CTA analyst who is not an expert in the healthcare specialization being studied most often performs CTA. Most CTA researchers have informally observed problems when subject matter experts become CTA analysts and interview other experts. CTA analysts who are also subject matter experts (SME) most often edit what they are told by other experts in CTA interviews so that the information they collect is consistent with their own experience and expectations. CTA analysts should have a general knowledge base to assist them in understanding what they observe and hear but most analysts have found that they should not have performed and/or taught the healthcare tasks they are attempting to identify. This clinical observation, widely accepted in the CTA community, would benefit from being tested in research. Analysts must also be skilled at listening and trained to accurately categorize and format the information they are receiving from SMEs during CTA interviews and the transcripts of interviews.

The 70 Percent Rule

Selecting the best healthcare "experts" is as important as the selection and training of analysts. Experts who engage in a CTA must have a record of consistent success and no serious errors while performing the tasks being captured for at least the three to five (or more) years required to become fluid and automatic. When possible experts should not have served as instructors on the tasks being analyzed. The reason for this requirement is evidence that experts who teach can't recall about 70 percent of their own automated decisions and analytical strategies but must describe an approach to students and so tend to fill in their memory gaps with assumptions that are often wrong or irrelevant. Most experts have served as occasional mentors but those who have worked primarily as instructors for a year or more should be avoided if possible.

Clark et al, (2008) describe a number of studies in healthcare and other areas that have reported this 70 percent gap phenomenon. All studies that have examined the issue of percent recall of decisions by experts have reported data within the 70 percent range, with one interesting exception. Yates, Sullivan and Clark (2011) hypothesized that healthcare experts ability to consciously remember decisions they make during procedures was based on the amount of discussion surrounding the procedure. In an interesting study they focused on two common trauma procedures, one of which was controversial (central venous catheter insertion) and being discussed openly and the other (open cricothyrotomy) was common and not controversial. They started the interviews with a free recall interview (e.g. “Describe all of the steps a physician would need to take in order to successfully implement cricothyrotomy or a central line”). After capturing free recall descriptions from each expert, they implemented structured CTA interviews and repeated the process. All transcripts from both segments of the interviews were coded and compared favorably for inter-rater reliability. Individual CTA transcripts where combined into a CTA “gold standard” summary of the action and decision steps reported by all of the SMEs. As they captured the action and decision steps for both procedures, the analysts noted the amount of new information captured from each new SME as they continued to conduct interviews. What they found was that experts free recall version of the OC procedure omitted 72 percent of decision steps but only 35 percent of the decision steps for the controversial central line procedure. What is most interesting is that seven years before this study was performed, another CTA study of the central line procedure conducted before it became controversial had found that experts omitted 70 percent of the decisions (Maupin, 2004). The informal comparison of the original Maupin CTA of the central line procedure and the more recent Yates, Sullivan and Clark CTA after it became controversial provides evidence for the hypothesis that controversial healthcare procedures may be significantly less automated and non-conscious than non-controversial procedures.

It is also interesting that experts in this and other studies are able to recall many more action steps (physical actions) than decision steps. It is assumed that the high recall of action steps may result from experts forming a mental image of their actions and describing the image. Since our decisions are not directly observable, even when they are conscious they may not lend themselves to images that represent thought processes. Table 1 describes the number of steps in the OC procedure that experts described when teaching the procedure. Table 2 describes the number of steps the same experts revealed during CTA interviews. Clinical knowledge refers to the amount of relevant conscious conceptual knowledge about the procedure (facts, concepts, processes, scientific principles) the surgeons could recall.

Table 1: Percent of OC steps described by trauma experts during CTA compared to the total steps in the procedure (based on Yates, Sullivan and Clark, 2011)

	Clinical Knowledge	Action Steps	Decision Steps	Total Steps
Surgeon A	29%	69%	30%	50%
Surgeon B	21%	42%	30%	34%
Surgeon C	28%	42%	30%	34%

Table 2: Percent of knowledge extracted during individual CTA interviews compared to the total steps in the procedure (based on Yates, Sullivan and Clark, 2011).

	Clinical Knowledge	Action Steps	Decision Steps	Total Steps
Surgeon A	71%	88%	60%	76%
Surgeon B	64%	65%	60%	66%
Surgeon C	64%	76%	70%	72%

Yates, Sullivan and Clark (2011) replicated previous studies by Chao and Salvende (1994) Wei and Salvende (2004) that found most of the required cognitive decisions can be captured from three to four experts. After three to four experts, diminishing returns reduce the utility of the time and effort invested in CTA interviews. Future research might examine the reasons why three to four experts have been found to be optimal for capturing most non-controversial decisions in all fields studied. It is likely that different experts focus consciously on different decisions but why should they each contribute about 1/3 of the reported decisions needed to perform a complex procedure?

It is also important to note that no one has found evidence to support the common assumption that recently trained practitioners in every field are more able to remember the decisions that must be made because they have not yet automated them. The available evidence more reliably supports the view that new practitioners are filling in gaps in their learning through trial and error though they may not always recognize error (Clark et al, 2008). Experts are interviewed individually to prevent arguments and negotiation over disputed points. Finally, healthcare educators must be cautious about the CTA method they select. Many methods are available but only a small number are evidence-based.

100 Versions of CTA But Only 6 Are Evidence-based

Yates (2007) analyzed all published descriptions of different methods of cognitive task analysis and identified approximately 100. Of the 100, Yates and Feldon (2008) concluded, "… only six … are formal methods supported by empirical evidence and standardized procedures that, if followed, predict knowledge outcomes." (p. 16). Clark et al (2008; 2010) suggest that of the six evidence-based CTA methods that are most compatible with instruction, most are implemented in five stages:

1. The CTA analyst identifies the target performance goals and reviews general knowledge about the task domain to become familiar with terms and processes.
2. Experts are asked to describe the sequence of tasks that must be performed in order for the performance goals to be achieved.
3. Multiple experts are asked to describe the step-by-step knowledge required to perform each of the tasks as well as the conceptual knowledge related to the steps.
4. The CTA analyst categorizes and formats the elicited knowledge and verifies it for accuracy and completeness by reviewing transcripts and crosschecking with multiple SMEs. In some CTA approaches, the analysts tests the elicited knowledge by providing it to novices and testing their performance.
5. The CTA analyst formats the edited knowledge for trainees by selecting one viable approach to teach that includes, for example, procedures that include action and decision steps, conceptual knowledge and job aids.

The result of this process is at least three different versions of the tasks and steps needed to achieve a performance goal (versions depend on the number of SMEs interviewed). After the separate lists are edited and corrected by all SMEs, the separate lists are condensed into one master list of steps (often called a "Gold Standard" CTA). This gold standard list consists of the sequence of tasks or sub-tasks that must be performed in order to achieve a performance goal and the action and decision steps necessary to achieve each task (see Figure 1 for an example of a CTA based task outline and Figure 3 for an example of a decision step for a central venous catheter insertion).

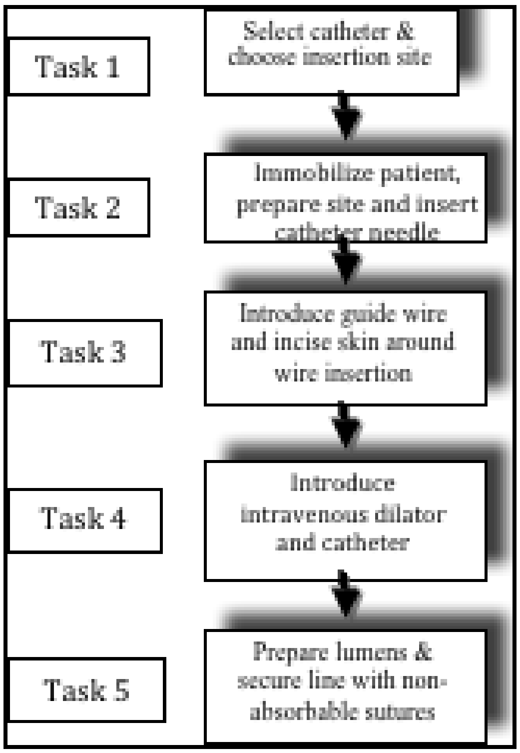

Figure 1: Example of a CTA based outline of tasks for the insertion of a central line (based on Maupin, 2004).

Example of an Evidence-Based CTA Method: The Concepts, Processes, and Procedures (CPP) method

Clark et al, (2008; Clark, 2006) have described one of the six evidence-based CTA methods that have most often been used in research on healthcare instruction (other methods are briefly described in Clark et al, 2008). The CPP (Concepts, Processes, Procedures) CTA method is based on the PARI method (Hall, Gott, and Pokorny, 1995) but modified to include the instructional design recommendations of Merrill (2002a, 2002b, 2006). The CPP approach implements the stages described above in a multi-stage process where a CPP trained analyst interviews at least three healthcare experts separately and asks them to describe the same procedure, followed by cycles of expert self- and peer-review. Clark and colleagues (Clark et al, 2008) have found that while experts tend to report similar cognitive strategies, each expert is also able to report new decisions and analytical strategies that the others have missed due to their automated knowledge.

Yates and Feldon (2009) have described the research that has led proponents of many of the evidence-based CTA methods to interview three to four experts. Yates and Feldon (2009) report evidence from multiple studies in many fields that indicate diminishing returns when interviewing more than four experts. Descriptions of the experiments where the CPP method was used are available in reports by Velmahos et al, 2004; Campbell et al, In Press; ;). Other evidence-based methods are described in Clark et all, 2008).

Interview

The initial, semi-structured CPP CTA interview begins with the CTA analyst describing the interview process for the SME so that they know what to expect. Many CTA analysts have informally reported the need to prepare all SMEs for interviews because the process can be frustrating for them due to the emphasis on very small segments of performance and the breaking down of their expertise into small steps. SMEs who were not adequately prepared have refused to cooperate with CTA interviews when they saw the first results of the time they have invested.

After the preparation, SMEs are first asked to quickly list or outline the performance sequence of all key sub-tasks necessary to perform the larger task being examined. The analyst is attempting to outline the sub tasks that must be performed and the sequence in which the SME performs them to outline the entire task being captured. Analysts have to urge SMEs to be brief and provide only an outline and avoid going into detail about any of the tasks.

Knowledge captured in interview. Once an outline has been captured, SMEs are asked to describe (or help the interviewer locate) at least five authentic problems that an expert should be able to solve if they have mastered the task. Problems should range from routine to highly complex whenever possible. These problems are used during training to demonstrate the application of the procedure collected as well as practice exercises and performance testing. Both the outline and the problems are continually developed and update during and after the CTA interviews. Once the outline and problems have been drafted, the analyst begins the CTA interview by focusing on the first subtask in the outline:

1. Action and Decision Steps for all Tasks: The expert is asked to describe the exact sequence of actions and decision steps necessary to complete each sub task described in the outline captured before the CTA begins. To help them, the analyst might ask them to remember and describe one or more memorable events where they used the procedure. Only when all action and decision steps have been captured, corrected by the SME and summarized does the analyst go to step 2;
2. Benefits and Risks: The expert is then asked to review the steps and describe the reasons for each procedure (benefits of performing, why it works, risks of not performing) for each task and also to indicate the steps that novices seem to have problems learning and/or performing. This information is used to create value for the procedure and to form a basis for the conceptual knowledge about the procedure that students need to learn so they understand why it should be expected to succeed.
3. Conceptual Knowledge Related to the Steps: Experts are then asked to describe all

concepts, processes and principles that are the conceptual basis for the experts' approach to each sub task. This information will be used to introduce and define new terms related to the procedure as well as describe the process where it takes place and the scientific principle(s) it implements;

4. Indicators and Contra-indicators: The conditions or initiating events that must occur to start the correct procedure. This information permits the description of the most important "indicators and contra indicators" for each procedure;
5. Tools: The equipment and materials required for each subtask. The analyst asks the SME for picture and examples than can be used during the training;
6. Sensory Requirements: The sensory experiences required (e.g., the analyst asks if the expert must smell, taste or touch something in addition to seeing or hearing cues in order to perform each sub task). This information helps instructional designers determine what part of the training can be presented via media that only present visual and aural information versus parts that must be practiced "live" in order to appreciate the smell, taste or motor learning needed; and
7. Quality Standards: The performance standards required, such as speed, accuracy or quality indicators to support the development of practice, feedback and testing.

Guided training design. This information is then formatted to identify the requirements of current "guided" instructional design based on Merrill's (2002a) specifications and Clark's (2004) GEL (Guided Experiential Learning) design. Each element of the CTA information captured is pulled into the design of a course and each lesson in the course (See Figure 3 for a crosswalk between the element of a CTA and the elements of a lesson design).

CTA Report	GEL Design
Task Objective	Learning objective
Benefits & Risks (Reasons)	Reason (benefits & risks)
Main Tasks & Procedures	Overview of course or lesson
Prerequisite Skills/Knowledge	Connections to prior knowledge
Concepts, Processes, Principles (CPP)	CPP required for performance
Action & Decision Steps	Demonstration of skill
Problems from SMEs	Practice on authentic problems
Checklist based on Steps	Feedback on practice
Checklist based on Steps + CPP	Whole Task Assessment

Figure 2: Crosswalk between the elements of a CPP CTA and the information required for a GEL Training Design.

The design of CTA based training depends in part on the media selected for delivery (e.g. computer, live instruction). Table 3 describes two of the decision steps that start the demonstration of the central line CTA described above.

Table 3: Example of a two decision steps for task 1, taken from the CTA on central line insertion (based on Maupin, 2004).

Step 1: Decide between two types of catheters

When:	Use this catheter
IF It is necessary (or likely) to infuse two or more types of fluids or the patient will be on long-term fluid administration or TPN.	THEN select Triple Lumen
IF Fluids need to be infused rapidly, or if a pulmonary artery catheter will be inserted.	THEN elect Cordis

Step 2: Decide among three sites for catheter placement.

When:	Choose this site:
IF the neck is accessible and can be moved, and the head and neck are free of excessive equipment.	THEN Jugular Vein
IF The neck is inaccessible or cannot be moved.	THEN Subclavian Vein
IF the neck is inaccessible, the subclavian veins are thrombosed	THEN Femoral Vein

and there is no injury to the IVC.	

Instructional demonstrations are often combined with video that illustrates each of the action steps and many of the decisions. Figure 3 provides an example of part of a demonstration segment for the CTA based central line training. The pictures illustrating the steps are icons that when clicked during training, play a video of the performance of each step.

Needle insertion technique

Begin insertion of the needle by using both hands.

Hold the plunger in the dominant hand and guide the needle (at correct angle and direction) with the non-dominant hand.

Once the needle is subcutaneous, place the thumb of your non-dominant hand at the point of insertion and the index finger in the direction of the target point.

Create constant suction by using the dominant hand to gently draw back on plunger of syringe while slowly advancing the needle into the vein.

Stop when venous blood enters the syringe barrel.

Figure 3: GEL instructional demonstration based on a central line CTA (following Maupin, 2004).

Assessment. Finally, Table 3 provides and example of a checklist created from the CTA task outline in order to assess the implementation of the procedure. Additional assessments must be developed to assess the learning of conceptual knowledge related to a procedure.

Table 4. Example of a checklist created from the CTA task outline in order to assess the implementation of the procedure based on Maupin, 2004.

Checklist for CVC placement performance review

ITEM		**Step #**	**Score**
1	Select appropriate catheter for condition	1	
2	Select appropriate site for insertion	2	
3	Place patient in appropriate position	3	
4	Sterilize the site using appropriate technique	4	
5	Glove and gown	5	
6	Inject 1% Lidocaine	6	
7	Locate correct point for needle insertion	AP A – C	
8	Start insertion with 2-hand technique	7	
9	Create anatomical position with non-dominant hand	7	
10	Stabilize syringe when reaching for wire	8	
11	Use correct technique for advancing wire into needle	9-10A & B	
12	Advance wire to correct depth	10A & B	
13	Withdraw needle	11	
14	Use appropriate scalpel technique to incise skin (0.5 cm)	12	
15	Introduce dilator appropriately into the incision	13A & B	
16	Advance the catheter correctly into the incision	15A-16A	
17	Maintain guide wire positioning w/ non-dominant hand	16A & B	

18	Position catheter at the correct depth	Append A-C	
19	Withdraw the guide wire	17A & 17B	
20	Prepare the lumen(s) correctly	18A-20AB	
21	Attach fluids to the catheter correctly	21	
22	Attach the line using non-absorbable sutures	22	

Future Research on Cognitive Task Analysis

CTA research suffers from many of the same problems as instructional design research. Despite a long history of development resulting in over 100 different application methods and many practitioners, CTA has not attracted the research interest it deserves. Part of the reason is that a number of practitioners have based business ventures on their own proprietary version of CTA and most are either not conducting research or are not sharing the results of their studies. In addition, nearly all CTA methods require a significant number of human judgments throughout the process of identifying experts and then capturing and formatting their knowledge. These judgments introduce variability that makes analysis, generalization and replication difficult if not impossible. Research progress in this area first requires some agreement to focus studies on one or more of the six CTA approaches whose methods have been described and whose advocates have conducted and published research in peer refereed journals (Yates and Feldon, 2008). Yet since none of the six evidence-based approaches have been unambiguously described, a first step in a systematic research program might be to conduct a CTA on expert practitioners of CTA using the same set of tasks and experts. The results of these CTA's would be carefully documented and then be incorporated into the same instructional design and development model and the resulting instruction presented to randomly selected groups of students representing the same population. A more conservative approach would present different versions of each element of a CTA method to assess its impact on learning and performance. An attractive test bed for these kinds of studies can be found in the large online academic programs offered my many universities and some businesses. When the same course is offered online multiple times in a week to thousands of students at once, it is possible to make many micro changes to a lesson and assess the impact quickly. The goal of this research would be to more clearly articulate the operational steps in different versions of CTA and provide evidence about the learning benefits of each version and/or its components.

Computational data mining research. It may also be possible to avoid some of the more challenging reliability problems associated with analyst interviews of experts by using computer data mining procedures (Cen, Koedinger and Junker, 2007). In these studies, computer-based healthcare problems would be provided to both experts and novices who vary in prior knowledge of the problems while their solution strategies and errors are captured and summarized automatically. It is likely that participants would have to be asked to explain the rationale for some of their problem-solving steps but keystroke analysis would increase the reliability of observations and the patterns identified would give a unique insight into expert and novice strategies.

Conclusions

The goal of all CTA methods is the identification of cognitive operations experts use to accomplish healthcare tasks. Current evidence suggests that when one of the six evidence-based CTA methods are applied to training or simulations, students learn about 30 percent more overall than with existing front end analysis or task analysis techniques. When PARI type CTA methods are used, average learning gains increase to 45 percent based on the most conservative Meta-analysis techniques. There are also indications that CTA trained healthcare professionals would be more attractive to employers and perhaps also to those who insure healthcare organizations. These gains and benefits may derive from evidence that CTA captures more of the automated, non-conscious knowledge that experts use effectively but can't recall or describe consciously. A growing evidence base suggests that experts are only aware of approximately 30 percent of the critical decisions and cognitive strategies they employ to solve problems due to limitations on working memory. Since experts design instruction and teach, about 70 percent of the information students or simulators need to perform or simulate healthcare tasks may be unintentionally omitted from current instructional materials and presentations. When evidence-based CTA is introduced at the front end of instructional design, learning increases and it is also likely that the errors committed by students and recent graduates of healthcare programs decrease.

At the present time, our healthcare educational system may not be taking advantage of the considerable problem-solving expertise developed by the top practitioners in every field. We seem to expect students to rediscover ways to solve about 70 percent of each healthcare problem when experts have already achieved a solution they could learn and apply. While CTA adds to the front end cost of healthcare instruction, what is the cost of implicitly requiring students to "fill in the blanks" and find their own solutions to problems through trial and error because their instruction is incomplete? What is the benefit of capturing more accurate and complete solutions to critical health care problems and transmitting them more completely to students who will become practitioners?

References

Besnard, D. (2000). Expert error: The case of trouble-shooting in electronics. Proceedings of the 19th International Conference SafeComp2000. Rotterdam, Netherlands. 74-85.

Campbell, J., Tiraplle, L., Yates, K., Clark, R. E., Inaba, K., Green, D., Plurad, D., Lam, L, Tang, A., Cestero, R., and Sullivan, M. (In Press). The effectiveness of cognitive task analysis informed curriculum to increase self-efficacy and improve performance for an open cricothyrotomy. Journal of Surgical Education.

Cen, H., Koedinger, K. R. and Junker, B. (2007) Is over practice necessary? – Improving learning efficiency with Educational Data Mining. In Luckin, R., Koedinger, K. R. and Greer, J. *Proceedings of the 2007 Conference on Artificial Intelligence in Education: Building Technology Rich Learning Contexts That Work*. Amsterdam: IOS Press. 511-518.

Chao, C-J., and Salvende, G. (1994). Percentage of procedural knowledge acquired as a function of the number of experts from whom knowledge is acquired for diagnosis, debugging and interpretation tasks. International Journal of Human-Computer Interaction, 6(3) 221-233.

Clark, R. E. (2004). Design Document For A Guided Experiential Learning Course. Final report on contract DAAD 19-99-D-0046-0004 from TRADOC to the Institute for Creative Technology and the Rossier School of Education, Los Angeles California. URL: http://www.cogtech.usc.edu/publications/clark_gel.pdf

Clark, R. E. (2006). Not knowing what we don't know: Reframing the importance of automated knowledge for educational research. In, Clarebout, G. and Elen, J. Avoiding Simplicity, confronting complexity: Advances in studying and designing (computer based) powerful learning environments. ISBN 90-77874-43-7. Sense Publishers, Rotterdam. 3 – 15.

Clark, R. E. and Elen, J. (2006). When less is more: Research and Theory Insights about Instruction for Complex Learning, in Elen, J. and Clark, R. (Eds.). Handling Complexity in Learning Environments: Research and Theory. Oxford: Elsevier Science Limited. 283-297.

* Clark, R. E. and Estes, F. (1996) Cognitive Task Analysis, International Journal of Educational Research, 25(5). 403-417.

* Clark, R. E., Feldon, D., vanMerrienboer, J., Yates, K, and Early, S. (2008). Cognitive Task Analysis. In Spector, J. M., Merrill, M. D., van Merrienboër, J. J. G., & Driscoll, M. P. (Eds.) Handbook of research on educational communications and technology (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates. 577-593.

Clark, R. E., Yates, K., Early, S. & Moulton, K. (2010). An Analysis of the Failure of Electronic Media and Discovery-based learning: Evidence for the performance benefits of Guided Training Methods. In Silber, K. H. & Foshay, R. (Eds.). Handbook of Training and Improving Workplace Performance, Volume I: Instructional Design and Training Delivery. New York: John Wiley and Sons. 263-297.

Crandall, B., & Gamblian, V. (1991). Guide to Early Sepsis Assessment in the NICU. Fairborn, OH: Klein Associates.

Crandall, B., & Gretchell-Leiter, K. (1993). Critical decision method: A technique for eliciting concrete assessment indicators from the "intuition" of NICU nurses. Advances in Nursing Science, 16(1), 42-51

Ericsson, K. A. (2004). Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Academic Medicine, 79(10), S70–S81.

Ericsson, K. A., & Charness, N. (1994). Expert performance: Its structure and acquisition. American Psychologist, 49(8), 725–747.

Sullivan, M. E., Yates, K. A., Baker, C. J., & Clark, R. E. (2010). Cognitive task analysis and its role in teaching technical skills. In Tsueda, S., Scott, D. and Jones. D. (Eds.). Textbook of Simulation, Skills and Team Training. Woodbury, CT: Cine-Med.

Feldon, D. F. (2004). Inaccuracies in expert self-report: Errors in the description of strategies for designing psychology experiments. An unpublished doctoral dissertation presented to the faculty of the Rossier School of Education, University of Southern California.

* Feldon, D. F. (2007) The implications of research on expertise for curriculum and pedagogy. Educational Psychology Review. 19, 91-110.

Gilbreth, F. B. and Gilbreth, L. M. 1919, Fatigue Study. New York: Macmillan.

Gladwell M. (2005). Blink: The power of thinking without thinking. New York, NY: Little Brown and Company.

Glaser, R., Lesgold, A., Lajoie, S., Eastman, R., Greenberg, L., Logan, D., Magone, M., Weiner, A., Wolf, R., Yengo, L. (1985). Cognitive task analysis to enhance technical skills training and assessment. (Final Report to the Air Force Human Resources Laboratory on Contract No. F41689-8v3-C-0029.) Pittsburgh, PA: Learning Research and Development Center, University of Pittsburgh.

Halfer, D. & Graf, E. (2008). Graduate nurse perceptions of the work experience. Nursing Economics, 24(3), 150-155.

Hall, E.M., Gott, S.P., and Pokorny, R.A. (1995). A procedural guide to cognitive task analysis: The PARI methodology. Brooks Air Force Base, TX: Manpower and Personnel Division, U.S. Air Force.

* Hoffman, R. R., & Militello, L. G. (2009). Perspectives on cognitive task analysis: Historical origins and modern communities of practice. New York: Psychology Press.

Hunt, E, Joslyn, S (2000). A functional task analysis of time-pressured decision-making. In Schraagen, Chipman, & Shalin (Eds.). Cognitive Task Analysis. Mahwah, New Jersey: Lawrence Erlbaum Associates. 119-132.

Klein, G. A., Calderwood, R. & Macgregor, D. (1989). Critical decision method for eliciting knowledge. IEE Transactions on Systems, Man and Cybernetics. 19(3). 462-472.

Lee, R. L. (2004). The impact of cognitive task analysis on performance: A meta-analysis of comparative studies. Unpublished Doctoral Dissertation, University of Southern California, Los Angeles.

Maupin, F. G. (2004). Comparing cognitive task analysis to behavior task analysis in training first year interns to place central venous catheters. Unpublished doctoral dissertation. Rosser School of Education. University of Southern California.

Merrill, M. D. (2002a). First principles of instruction. Educational Technology Research and Development, 50(3), 43–59.

Merrill, M. D. (2002b). A pebble-in-the-pond model for instructional design. Performance Improvement, 41(7), 39–44.

Merrill, M. D. (2006). Hypothesized performance on complex tasks as a function of scaled instructional strategies. Elen, J. and Clark, R. (Eds.). Handling Complexity in Learning Environments: Research and Theory. Oxford: Elsevier Science Limited. 265-281.

Mislevy, R. J., Breyer, F. J., Almond, R. G. & Johnson, L. (1998) A cognitive task analysis with implications for designing simulation-based performance assessment. National Center for Research on Evaluation, Standards and Student Testing (CRESST). University of California, Los Angeles.

Schneider,W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: 1. Detection, search, and attention. Psychological Review, 84, 1–66.

* Schraagen, J. M., Chipman, S. F., and Shalin, V, L. (2000). Cognitive Task Analysis. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Toefl-Grehl, C. (In preparation). Cognitive Task Analysis: A Meta-Analysis of Studies. School of Education, University of Virginia.

* Velmahos, G. C., Toutouzas, K. G., Sillin, L. F., Chan, L., Clark, R. E. Theodorou, D. and Maupin, F. (2004) Cognitive task analysis for teaching technical skills in an inanimate surgical skills laboratory. The American Journal of Surgery. 18. 114-119.

Wegner, D. M. (2002) The illusion of conscious will. Cambridge, Mass: MIT Press.

Wei, J., & Salvendy, G. (2004). The cognitive task analysis methods for job and task design: Review and reappraisal. Behaviour & Information Technology, 23(4), 273-299.

Wheatley, T., & Wegner, D. M. (2001). Automaticity in action. In N. J. Smelser & P. B. Baltes (Eds.), International encyclopedia of the social and behavioral sciences (pp. 991-993). London: Pergamon.

Workforce Connections Inc. (2011) Business Survey Outcomes. Available when this chapter was published at: http://www.workforceconnections.org/Business%20Survey%20Outcome%20REPORT%20Final.pdf

Yates, K. A. (2007). Towards a Taxonomy of Cognitive Task Analysis Methods: A search for cognition and task analysis interactions. Unpublished doctoral dissertation presented to the faculty of the Rossier School of Education at the University of Southern California.

Yates, K. A. and Clark, R. E. (In Press). Cognitive Task Analysis. In J. A. C. Hattie & E. M. Anderman (Eds.) International Handbook of Student Achievement. New York, Routledge.

* Yates, K. A. & Feldon, D. F. (2008). Towards a Taxonomy of Cognitive Task Analysis Methods for Instructional Design: Interactions with Cognition. Paper presented at the Annual Meeting of the American Educational Research Association, New York City, New York.

Yates, K. A., Sullivan, M. and Clark, R. E. (2012). Integrated studies in the use of Cognitive Task Analysis to capture surgical expertise for Central Venous Catheter Placement and Open Cricothyrotomy. American Journal of Surgery. 1-5.

Acknowledgements

Author Information

Richard E. Clark

Rossier School of Education

Department of Surgery, Keck School of Medicine

USC Center for Cognitive Technology

3664 Hightide Drive

Rancho Palos Verdes, CA 90275, USA

(310) 377 7220

(888) 768 3885

clark@usc.edu

www.cogtech.usc.edu