

Cognitive Task Analysis

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Introduction

Cognitive task analysis (CTA) refers to a variety of methods used to elicit and represent knowledge and skills experts use to perform complex tasks. Multiple experts are consulted to capture the knowledge, cognitive processes, and goal structures they use to solve complex problems and perform difficult tasks (Chipman, Schraagen, & Shalin, 2000). Evidence suggests that some CTA methods capture more complete and accurate descriptions of the performance objectives, equipment, conceptual and procedural knowledge and performance standards required to replicate expert performance for complex tasks than “self report” or behavioral task analysis methods (Clark, Feldon, van Merriënboer, Yates, and Early, 2008). The results of CTA are used in a variety of learning and human-machine applications, most often to develop instructional content and expert systems.

Cooke (1994, 1999) identified over 100 CTA methods and classified them according to the method of eliciting knowledge (i.e., observations and interviews, process tracing, formal models, and conceptual techniques.) Other researchers have categorized CTA methods by intended application, knowledge representation, and appropriate uses (Essens, Fallesen, McCann, Cannon-Bowers, & Dorfel, 1995; Militello, 2001; Wei & Salvendy, 2004). These classifications provide some guidance for choosing a specific method for specific purposes, but only when the practitioner is familiar with underlying theory and mechanisms.

Research Evidence

Clark et al. (2008) describe a relatively straightforward CTA method demonstrated to be effective for capturing both the conceptual knowledge and procedural skills experts use to solve complex problems. This method uses semi-structured interviews with multiple subject matter experts (SMEs) who

have demonstrated consistent and successful proficiency in performing a task over a long period of time and who have not served as instructors (because instructors tend to report what they teach but not necessarily what they do). With this method, CTA is generally performed in stages in which a trained specialist first interviews at least three SMEs with recent experience to capture:

1. The sequence of stages to perform a complex job or task.
2. The equipment or materials required to perform the job or task.
3. The procedural steps about *when* and *how* to make decisions and perform actions.
4. The conceptual knowledge (concepts, processes, and principles) required as pre-requisite knowledge to perform the complex job or task.
5. Quality or proficiency standards required for expert performance.

The experts edit and correct their own information, which is then aggregated into one “gold standard procedure”, in which any differences are resolved by the group or by a fourth, more senior, expert.

Historically, CTA can be traced to the late 1800s during the development of ergonomics, psychotechnics, and, in the early 20th Century, behavioral task analysis, especially the time and motion studies conducted by Taylor (1911) and Gilbreth (1911) (see Hoffman & Militello (2009) for an extensive historical review). Although this research, and the management systems that originated from it, recognized cognitive components, such as planning and choosing (Gilbreth’s system included a stick figure symbol resembling Rodin’s statue of *The Thinker*), it was not until the 1930s that jobs began to shift away from coordinated physical tasks to those that required cognitive skills, such as deciding, analyzing, and evaluating information. Research continued

during the second half of the 20th Century in both cognition and applied psychology, which led to deeper understanding of the science of learning and human-machine interactions. During the past 25 years, advances in cognitive science and human performance research have resulted in the development of CTA methods to capture the decision steps and other analytical processes, in addition to the physical action steps, that have the potential of replicating expert performance in problem solving, programs of instruction and expert systems.

The importance of CTA to capture expert performance of complex tasks can be further understood by examining expertise in any knowledge domain, which by its nature, is acquired as a result of continuous and deliberate practice in solving problems in a specific domain (Ericsson, Krampe, & Tesch-Römer, 1993). As new knowledge is acquired and practiced, it becomes automated and unconscious (Anderson & Lebiere, 1998). For example, once we learn how to drive, we can do so without thinking much about the actions and decisions we make to navigate even difficult traffic and instead are able to talk to passengers or listen to the radio. Automated knowledge helps free our minds to handle novel problems. Yet it also causes experts to be unable to completely and accurately recall the knowledge and skills that comprise their expertise—even though they can solve complex problems using the knowledge they can't describe. This results in significant, though unintended, omissions when experts train novices or try to communicate their expertise to others, which can negatively impact instructional efficiency and lead to subsequent difficulties for learners (Chao & Salvendy, 1994; Feldon, 2007; Hinds, 1999). A number of studies have reported for example that experts omit about 70% of the important decisions they make when describing a complex task (Feldon & Clark, 2006).

A review of the literature reveals that CTA-based instruction is not common in K–12 settings (Yates & Feldon, 2008). As Jonassen, Tessmer, and Hannum (1999) note, although task analysis of *any* kind is the first stage in the process of designing and developing instruction, it is often the “most poorly executed, or simply ignored component of the instructional design process” (p. vii). A major goal of education is to prepare students for flexible adaptation to problem solving in new settings (Bransford, Brown, & Cocking, 2004, p. 77), which we consider an important component of academic achievement. In order to achieve flexible adaptation, instruction must be based not only on in-depth descriptions of the knowledge and skills for “when and how” to perform highly complex tasks in a variety of contexts, but also the “what and why” knowledge, that is, the concepts, processes, and principles required to adjust task performance for unexpected and novel events. However, before instruction to meet these requirements can be designed and developed, the knowledge and skills that highly successful experts use to perform complex tasks must first be captured using CTA.

Contrasted with K–12 learning environments, CTA has been shown in a wide variety of studies to effectively capture

experts' knowledge and skills when performing complex tasks and transfer that expertise to increase achievement in professional education. For example, a number of studies in medical education have documented that medical students and interns receiving CTA-based training showed higher levels of competence performing various medical tasks when compared to traditional expert-led surgical skills education (Maupin, 2003; Sullivan, Yates, Baker, & Clark, in press; Tirapelle, 2010; Velmahos et al., 2004).

Other examples of CTA effectiveness can be found in military applications, such as diagnosing and troubleshooting complex computer systems, which often must be performed under severe time constraints in high stakes operational conditions, have high stake consequences, and must achieve a high degree of speed and accuracy. In a study conducted by Schaafstal, Schraagen and van Berlo (2000) a series of cognitive task analyses was conducted to develop and test a structured troubleshooting training method. The results demonstrated that the experimental group in the structured training solved twice as many malfunctions, in less time, than those trained in the traditional way, leading to a reduction not only in training time, but the costs of troubleshooting overall. Similar applications of CTA have been effective for expert analysis of military intelligence for stability and support operations (Pfautz & Roth, 2006) and to identify decision requirements for launching AEGIS cruise missiles in high-stress situations (Cohen, Freeman, & Wolf, 1995; Klein, Kaempff, Thorsden, & Miller, 1997).

CTA has been successfully used in business environments, for example, in studies comparing training methods for learning how to use spreadsheet software (Merrill, 2002). Three courses were developed—one based on guided demonstrations found in a commercially available product, another based on discovering solutions to authentic problems, and a third based on CTA conducted with a spreadsheet expert. In post-test scores, the CTA group achieved 89% compared to 64% for the guided demonstration, and 34% for the discovery condition. The CTA group also completed the problems in less time—only 29 minutes compared to 49 minutes for the guided demonstration, and more than 60 minutes for the discovery group.

To examine the generalizability of CTA methods to improve training performance, Lee (2004) conducted a meta-analysis of studies published between 1985-2003 across a broad spectrum of disciplines. The results showed effect sizes of between .91 and 1.45, all considered “large” (Cohen, 1992), and a mean effect size of $d = +1.72$ representing a post-training performance gain of 50%.

Although CTA-based instruction has been shown to increase achievement, a well-known criticism of conducting CTA properly is that it consumes time and resources. However, this may be a shortsighted perspective, as the benefits of CTA appear to outweigh the cost. In one study, Clark and Estes (1996) compared the use of traditional task analysis with cognitive task analysis for training in a large European organization on safety and emergency pro-

cedures. Development of the training using CTA required 85% more time; however, the CTA-based course resulted in a time-savings of 2.5 person years, because the training could be offered in one day compared with 2 days in the previous course. Similar time-savings with CTA-based instruction were found in the Velmahos et al. (2004) and Merrill (2002) studies.

Summary and Recommendations

Research in CTA methods continues to evolve, with a particular emphasis on reducing the time and resources required to elicit and represent expert knowledge and skills for complex tasks, without sacrificing the validity and reliability of the results. In addition, Yates (2007; Yates & Feldon, in review) has suggested research toward developing a taxonomy of CTA methods, in which a systematic program of study might identify the active ingredients of effective CTA methods to validly and reliably achieve the desired conceptual and procedural knowledge required to prepare students to solve problems in an increasingly complex world.

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