

A One-Day Workshop for Teaching Cognitive Systems Engineering Skills.

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## Introduction

The goal of this chapter is to describe a method for teaching Cognitive Systems Engineering (CSE) to non-specialists. We designed a workshop to teach the activities that are required to accomplish CSE when designing a system. This introductory section explains how this method, using a workshop structure, came into existence and what it was intended to achieve. The next section describes the framework and content of the workshop, which we eventually presented at three different conferences. The final section provides reflections on our overall project to support the teaching of CSE.

Our effort began in the 2003 timeframe as a simple exploration of similarities and differences between different CSE approaches. We were concerned about the fragmentation of the field. Hoffman et al. (2002) had used a concept map to show the different facets of CSE. It revealed the diversity of the field. Researchers and practitioners had developed contrasting CSE approaches and methods, and competing brands such as Cognitive Work Analysis, Applied Cognitive Work Analysis (ACWA), Situation-Awareness Oriented Design, Decision-Centered Design (DCD), and Work-Centered Design. System developers seemed confused about what CSE was supposed to achieve and which particular approach to adopt.

In response to this confusion, we initiated a series of lunch meetings at a favorite Vietnamese restaurant, taking advantage of our being co-located at the time in Dayton Ohio. Gavan Lintern, who was then with General Dynamics, was a staunch advocate for Cognitive Work Analysis. Laura Militello and Gary Klein, both working at Klein Associates at the time, were equally staunch advocates for Decision-Centered Design. Cindy Dominguez was, at that time, a Lieutenant Colonel at Wright-Patterson AFB and was more interested in seeing CSE

applied broadly in practice than in advocating for any specific approach. So we had two bases covered, CWA and DCD, plus a referee.

These meetings resulted in a generic description of the activities required for a CSE effort to succeed. Different approaches might employ different methods – Abstraction Hierarchies for CWA, Cognitive Task Analyses for DCD — but the game plan was, for the most part, the same. We published two articles to describe this generic account of CSE (Militello et al., 2009a; Militello et al. 2009b) but then wondered whether we might develop an introductory workshop for CSE. Even if we never ran the workshop, the process of designing it might prove instructive. What should be included?

We agreed that the workshop should be experiential, with minimal lecturing. Other CSE practitioners had offered workshops that explained specific methods and compared different approaches. We did not think workshop participants at an introductory level would care about the nuances that differentiated one approach from another. We imagined they would want to gain a sense of why CSE could be useful and how to plan and accomplish a CSE effort. We agreed that we wanted to get the participants to practice CSE skills by the end of the workshop and to that end, we would need to illustrate a full CSE cycle within the time available.

We settled on a single-day workshop largely because it would fit the full-day conference formats that were commonly in use but in addition, we believed that if we spilled into a second day it would be too easy to defer tough decisions about what to include. We believed the discipline of a single-day format would help us maintain focus and priorities. Thus we decided to run the participants through an entire CSE effort in a single day – a whirlwind tour of the topic. In describing the results here, we hope to provide a view of CSE as a field and provide insights into how to familiarize people with its practice.

## **Designing the Workshop**

The core of the workshop would have to be an assignment that called for CSE. We considered several different possibilities. One option was to design a kitchen. Another option was to redesign the Hertz Neverlost system (a GPS device for helping rental car customers navigate in unfamiliar cities). We initially settled on the kitchen design exercise as one that would allow participants to immerse themselves in the design problem without any prior need for familiarization with the problem domain. We anticipated that workshop participants would be able to link kitchen design issues to the workshop exercises that were to be introduced through the remainder of the day.

We chose to focus on Decision-Centered Design, not because we were all convinced it was the best CSE approach, but because we wanted the participants to leave the workshop with some level of usable skill that would allow them to initiate a CSE effort when they returned to their workplace. The theory and method of Decision-Centered Design seemed to fit that constraint. From a theoretical perspective, Decision-Centered Design is closely aligned with the concept of macrocognition, emphasizing the study of cognition in real-world settings involving multiple players, shared resources, risk, and often competing goals (Klein et al, 2003). Decision-Centered Design involves use of Cognitive Task Analysis interviews to identify the most important and challenging decisions in performing a task, capturing the factors that make these decisions difficult and the types of common errors people make, identifying the critical cues needed to make the decisions, and then orienting the design activities towards supporting these decisions, reducing the barriers, and highlighting the critical cues (Militello & Klein, 2013). Decision-Centered Design offers a comprehensive story that fits well into a one-day format

without straying into complexities and subtleties that would distract participants from the unifying theme of CSE.

The one-day whirlwind strategy prevented us from discussing the relative merits of different CSE approaches, which might have detracted from the message. Although we considered ways to fit Cognitive Work Analysis into the day, Gavan Lintern, our CWA champion, offered that we should avoid it. He thought that it alone would be too challenging to bootstrap people to a working level in one day, and that putting it adjacent to the ideas of Decision-Centered Design in an introductory workshop would end up confusing people.

The initial workshop, put on by the four authors plus Corey Fallon, was entitled “The Road to Cognitive Systems Engineering,” and was presented in 2008 at the annual meeting of the Human Factors and Ergonomics Society. It went fairly well. There were 16 attendees. In rating the overall workshop quality on a 5-point scale (1= Poor: of no redeeming value and 5 = Excellent: among the best workshops offered anywhere), 3 participants rated it a 5, 11 rated it a 4 (Good: very important information packaged to meet participants’ needs and presented clearly) and 2 rated it a 3 (Acceptable: Conveyed key issues clearly). On average, the participants rated the workshop 4.0 (out of 5) for overall quality. We all believed that it could be improved. In particular, we thought the kitchen design exercise was not as effective as we had anticipated, mainly because participants had not actively engaged in kitchen work during the workshop and in particular, had not teamed with other people in a kitchen setting.

We revised the workshop by substituting an information-management exercise that had participants either working in small teams or observing teams as they worked. This exercise had the particular advantage of allowing workshop participants to gather their own activity data that they could then use in the subsequent workshop exercises throughout the day.

We next had the opportunity to present the workshop at the International Symposium on Aviation Psychology in April 2009. There were 14 participants. This conference used a 7-point evaluation format (with 7 being the highest). The overall evaluation received one rating of 7, 8 ratings of 6, 4 ratings of 5 and one rating of 4, for an average of 5.67 out of 7. These evaluations suggested that the workshop needed additional development.

After further modification, we presented the CSE workshop again at the Human Factors and Ergonomics Society meeting in October 2009. This time the workshop received extremely high evaluation scores – the highest any of us had ever experienced. There were 12 attendees. In rating the overall workshop quality on a 5-point scale (1= Poor: of no redeeming value and 5 = Excellent: among the best workshops offered anywhere), 8 participants rated it a 5, 3 rated it a 4 and one rated it a 3. On average, the participants rated the workshop 4.6 (out of 5) for overall quality, 4.3 for usefulness, 4.3 for value, and 4.7 for quality of the instructors.

This chapter describes the approach we took as we tried to boil the CSE process down to essentials. For further reference, we have made the workshop slides available on a Workshops page of [www.cognitivesystemsdesign.net](http://www.cognitivesystemsdesign.net).

### **Workshop activities**

This workshop description focuses on the third offering, the one that we believe was the most effective.

Introduction (30 minutes). In the workshop introduction, our intent was to immediately engage participants to signal to them that the workshop would be an interactive rather than a passive learning experience. We started by asking participants to introduce themselves and to describe a project or context in which they might apply CSE methods. From there, we provided a brief definition of CSE and a quick overview of the five most commonly used frameworks: Cognitive

Work Analysis (Rasmussen, Petjersen, and Goodstein, 1994; Vicente, 1999); Applied Cognitive Work Analysis (Elm et al., 2003); Situation-Awareness Oriented Design (Endsley, Bolté and Jones, 2003); Decision-Centered Design (Hutton, Miller and Thordsen, 2003); and Work-Centered Design (Eggleston, 2003)

Although, there was a strong temptation to begin with a lecture that would thoroughly lay the groundwork (i.e., theoretical background, methods, commonalities and differences across approaches, labels and definitions, etc.), we chose to present just enough information to orient the participants at this point. The slides contained key representations from each CSE approach and references for further reading.

We explained that because the presenters were most familiar with Decision-Centered Design, we would use methods closely associated with Decision-Centered Design throughout the workshop.

After these orienting slides, we advised the participants that they would be asked to conduct a CSE project to support team decision making and other cognitive work in a command and control environment over the course of the workshop. Figure 1 describes this task. We knew from previous experience that grounding methods in even a hypothetical project makes it easier for participants to think critically about how the methods will work. Having a goal in mind allows participants to think more concretely about how each phase (data collection, analysis, design) informs the next. We limited ourselves to 30 minutes for these introductory materials, so that we could move quickly to the first interactive exercise.

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Figure 1.



**Mission Statement:  
Supporting Small Team Decision  
Making in a Command & Control Task**

You have been commissioned to undertake a CSE project involving the research and design of technology and training concepts that support team decision making and other cognitive work in a command and control environment.

An aerospace engineering company (who wishes to remain anonymous) has failed miserably in its first attempt to do so, and has engaged HFES to conduct a workshop in October, 2009 to gain fresh insights and recommendations to support this problem space.

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Information Management Exercise (1 hour). We employed an exercise designed to pull participants deeply into a stressful team situation, so that they then could practice the CSE methods taught during the workshop, using themselves as subject matter experts. This exercise also broke down barriers between participants who did not know each other, and facilitated a personal understanding of what it means to experience high-stress, time-critical team decision making under uncertainty, as well as what it means to study and understand how people act in such situations.

This exercise enabled facilitators to place participants with varied backgrounds into a short-term context of shared, high stakes decision making under uncertainty and time pressure.

To conduct this exercise, at the outset we asked workshop participants for volunteers willing to act as military decision makers. This small group of 4-6 volunteers was organized in a hierarchical set of roles, and told that it was their job to understand, from information provided,

where friendly and enemy forces were, predict their future actions, and to command friendly forces based on this knowledge. One volunteer was asked to assume a team-leader role.

The exercise was facilitated by a workshop instructor who had practiced the tone and pacing of instructions to provide a realistic, pressured experience. The team leader was given a fast-paced set of message injects, called spot reports, along with a map of the space where friendly and enemy forces were active, as shown in Figure 2 below. The team was required to act on their assessment of the situation based on these messages. The spot reports might say that a UAV detected two red vehicles in sector D3, or that a friendly force requires resupply. Example messages are shown in Table 1 below.

Figure 2.

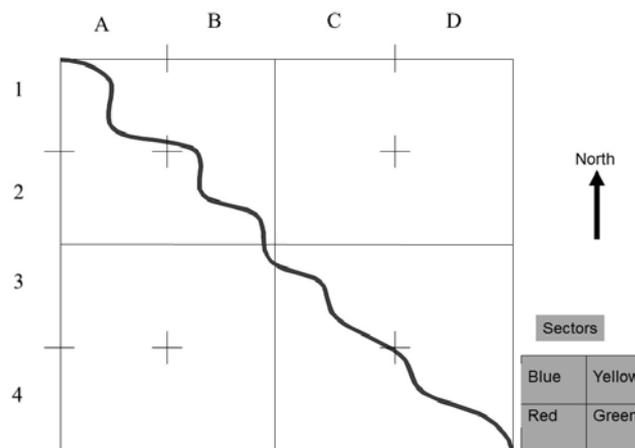


Table 1.

<b>To/From, Time</b>	<b>Subject</b>	<b>Message</b>
<b>00:00</b> <b>To: Sunray, From 1<sup>st</sup></b> <b>Platoon</b>	Spot Report	1 <sup>st</sup> Platoon relocated to A2
<b>00:00</b> <b>To: Sunray, From 2<sup>nd</sup></b> <b>Platoon</b>	Spot Report	2 <sup>nd</sup> Platoon relocated to A3
<b>00:00</b> <b>To: Sunray, From Hawk</b>	Spot Report	Hawk reports 2 unknowns in D4
<b>03:00</b> <b>To: Sunray, From</b> <b>DIVMAIN</b>	Movement	<b>AUTOMATED MESSAGE:</b> Sensors detect movement

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Fourteen such messages were initially handed to the team leader by the facilitator; then three minutes elapsed, and another set of messages was delivered, followed by repeated cascading sets of messages delivered according to a pre-determined schedule.

As these reports accumulated rapidly, the team leader quickly realized the need to set up a process for triaging message priority and updating the situation on the map, as well as the need to allocate roles to team members and to better organize the team. All the while, the facilitator continued to pressure the leader and the group. Some spot reports provided solid situation awareness while others were designed as distractors or were ambiguous in the information provided, thereby increasing the uncertainty and adding to the chaos.

While the information management exercise was underway, the attendees who were not playing a role on the team were assigned to two observer groups. One group was instructed to just watch the decision making team and note events of interest, while the other group was instructed to watch for specific macrocognitive functions and processes: the decisions the group made, shifts in the situation awareness of the team, problems and workarounds in coordinating the team.

After all messages were delivered and the team leader was asked for a solution (recommended action to higher headquarters), we debriefed the exercise. Each observer group and the decision makers described decision challenges, assessment challenges, sensemaking challenges, and organizational issues. Observers in each group then compared notes on whether having a structure helped them to see and record in different ways than having no structure.

Next, the entire group shared experiences across teams, with the facilitator noting the aspects of team cognition that were already covered, and adding items from the set described in the previous paragraph. (The set of topics can and should change in future workshops depending on the team cognition interests of the organizers.)

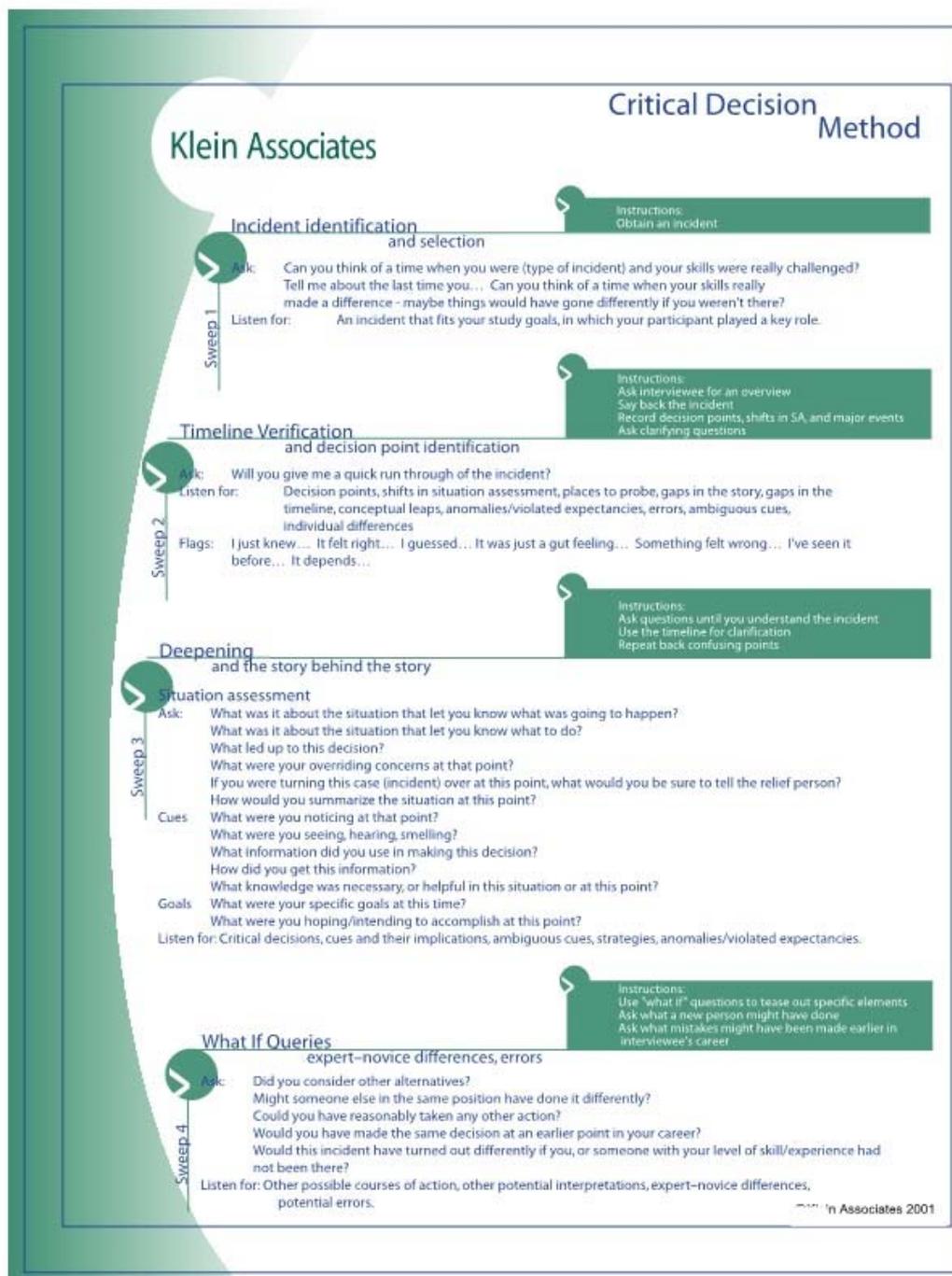
Having experienced this exercise, workshop participants were visibly more relaxed, communicative, and engaged than when the workshop began. More importantly, each participant had experienced or observed a situation with characteristics like those faced by real-world high stakes decision makers and observers, a situation similar to those that CSE practitioners need to understand and support in their everyday work.

Critical Decision Method overview and demonstration (75 minutes). Next, we introduced the Critical Decision method as a technique for uncovering decision requirements. The Critical Decision method (Crandall, Klein & Hoffman, 2006) is an incident-based method for capturing

subtle aspects of expertise. It provides an understanding of how people think in the context of a lived event, given that people are generally unable to report accurately on their mental processes (Nisbett & Wilson, 1977). We highlighted the value of these incident-based methods for increasing recall, facilitating discussion, encouraging a first-person perspective, and evoking detailed memories. We provided a job aid. Figure 3 summarizes the four sweeps of the Critical Decision method. Then we conducted a demonstration interview with a volunteer from the small team that had participated in the information management exercise.

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Figure 3.



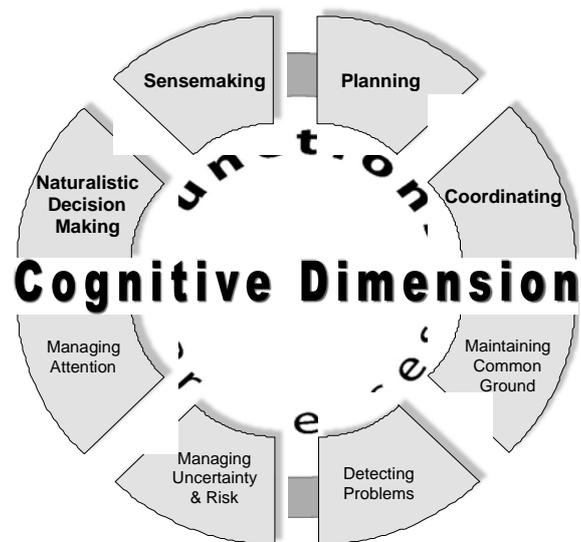
The workshop facilitator elicited an incident (sweep 1) and drew a timeline (sweep 2). Then the facilitator asked workshop participants to follow up with deepening questions to probe the challenges, cues and situation awareness (sweep 3) and hypotheticals such as ways that a novice might blunder and differences between experts and novices (sweep 4). All participants were asked to take notes during the interview to inform the design of a small-team decision-making tool (Figure 1).

In earlier workshops, we had conducted the entire demonstration interview with participants observing. We found this hybrid approach in which the facilitator begins the interview and then opens it up to participants to ask additional questions to provide a nice balance. Using this approach, participants have an opportunity to observe the facilitator's questioning style and strategy for structuring the interview, but also have an opportunity to take the interviewer perspective first-hand and practice it.

Macro cognition lecture (15 min). After encouraging participants to collect both observation and interview data from the information management exercise, we recalled the goals of CSE and introduced macrocognition as a framework to guide CSE, as shown in Figure 4. We included a brief discussion of how the macrocognitive functions and processes link to the cognitive work observed in the information management exercise. Our intent was, again, to limit the amount of theoretical lecture, while providing orienting information that would help participants identify useful decision requirements to support small-team decision-making in the context of command and control.

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Figure 4.

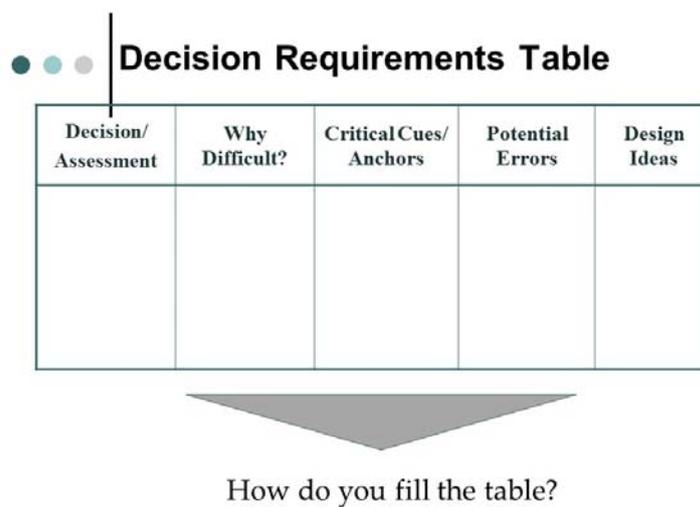


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Decision Requirements Table (1 hour). To transition from data collection to data analysis, we introduced the decision requirements table (Figure 5) as a representation technique to organize and highlight key decisions. We asked participants to refer to their observation notes from the information management exercise and the follow-up interview to develop a decision requirements table. After a few minutes of independent work, they moved into small groups to share findings and develop an integrated decision requirements table.

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Figure 5.



Design Exercise (1 hour). For the design exercise, we reminded participants of their project goals (see Figure 1), and asked them to spend an hour in their small groups discussing concepts for a tool to facilitate team decision making in the context of command and control. The tool should directly support the decision requirements identified in the exercises earlier in the day.

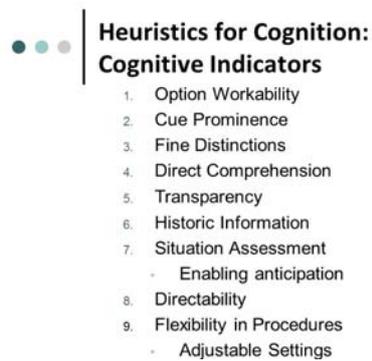
We provided large sheets of paper and pens to help the groups articulate and illustrate their design concepts. Groups were informed that they would have the opportunity to brief their design concepts at the end of the hour.

Cognitive Performance Indicators (25 min). No design process is complete without some type of assessment. We introduced participants to a Cognitive Performance Indicator (CPI) tool (Long & Cox, 2007; Wiggins & Cox, 2010), a heuristic evaluation approach with cognitive research underpinnings, for use in assessment of user interfaces. Providing each participant with a job aid

handout, we explained each of the nine indicators, which are listed in Figure 6, and provided real-world examples of how they act as a filter for identifying strengths and issues with a system's support for cognitive work.

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Figure 6.



As an example, the transparency indicator provides an assessment criterion that a system should provide access to the data it uses and show how it arrives at processed data. The real-world connection: robotic (and other) systems often have multiple algorithms behind displayed information. Users may or may not trust the numbers displayed, depending on how much transparency is afforded for users to validate information. (See Wiggins and Cox, 2010, for a complete description of this approach.) We provided details and examples of how in practice to apply the indicators to assess systems' support of user cognition.

To make a clear linkage to the workshop goals and the conceptual stance underlying the DCD approach to CSE, we tied the CPIs back to macrocognition functions and processes, and emphasized that the approach should be tailored to a particular domain — only a subset of the indicators might be chosen to apply to any given system, depending on that system's functions

and goals. Also, we offered options for using the CPI approach at the start of an effort in order to clearly understand what issues users experience with an existing system, as well as applying it after this CSE methodology had led to new interface designs, in a heuristic evaluation manner (see Nielsen & Molich, 1990).

Redesign (25 min). To encourage reflection on this CSE process, we asked participants to consider how they might re-design the data collection process. We asked them to use hindsight to suggest how they might strengthen the observation and interview approach used in the workshop. We also asked them how they would, with hindsight, re-design the initial mission statement shown in Figure 1. This discussion topic elicited thoughts about both the number of observations/interviews, and the content of each. Building on their experience developing Decision Requirements Tables and design concepts, the workshop participants identified new questions and information gaps.

### **Reflections**

In our retrospective analysis of the success of this enterprise we reflected on three issues; whether the desire for this sort of experience within the human factors and cognitive engineering community was at the level we imagined, whether the participants in the workshop remained engaged and interested throughout the day, and whether our particular workshop format allowed workshop participants to develop a self-sustaining level of skill.

Was there a perceived need? The workshops were well-attended and the participants expressed immediate needs for learning more about CSE; therefore we would answer yes.

Did the participants remain engaged and interested throughout the day? We recalled our own experiences as participants in workshops where we have been promised a good deal of class

activity but where that promise remained unfulfilled because the workshop presenters spent most of the available time doing the talking. In reflecting on those experiences, we resolved to make our workshop heavily interactive. The initial exercise was challenging. Every participant had a job to do and, as far as we could tell, became deeply involved. After this initial exercise, further analysis and design exercises throughout the day drew on the participants' experiences of this first exercise, thereby maintaining a narrative through the day that was only briefly interrupted by short presentations of didactic material. Indeed, the demeanor of the workshop participants throughout the day and their comments on the assessment sheet suggest that they enjoyed the day and remained engaged with the material. We believe that beginning with the initial exercise and subsequently, the frequent use of data from that exercise in analysis and design exercises throughout the day was a key to this continuing engagement.

Did the participants learn? As a team of five, we distributed ourselves around the room during exercises and monitored progress. By our own judgment, we saw participants improving in their skill throughout the day. All of the exercises were successful and all participants seemed to be contributing to the quality of the work. In our judgment, workshop participants generally acquired a level of skill with the methods that make it possible to apply them to rather straightforward problems and by that method, gain sufficient experience that they would be able to apply them effectively in their ongoing projects.

We believe that the interactive nature of the workshop was crucial. The exercises expanded on a consistent theme throughout the day in a manner that served to keep participants engaged and we discussed the exercises as strategies for applying CSE methods in the didactic material in order to reinforce the lessons.

The experiential exercises also seem crucial to the success of the workshop. We had discussed several types of exercises. The one we chose for the second and third workshops had a game-like quality in which the exercise team had to process disorganized (and sometimes distracting) information to develop a plan. It had a military theme and while we think the structure worked well, we suspect that specialist groups (such as in health care or process control) might respond better to an exercise that captured some elements of their special domain.

Our goal for the amount of material that we would introduce was somewhat modest but at the end of the day, we could see that our workshop participants were satisfied. We believe that any attempt to pack more ideas into the day would diminish the experience.

### **Conclusions**

Our workshop was stimulated by the thought that CSE is a relatively unfamiliar discipline and that very few university programs teach its theories and methods. Practitioners have become proficient by reshaping their existing capabilities, often drawn from human factors science, cognitive science or engineering, to the practice of cognitive systems engineering. Most practitioners have essentially learned on the job.

In the development of this workshop, we imagined that some of those who had learned on the job would appreciate an introductory experience that laid out a foundation and some basic methods in an organized and engaging fashion. We pondered the alternatives. Returning to university for a couple of semesters would be entirely impractical for all but a very few. A program of several days duration, such as the one conducted by the University of Michigan for human factors, could fill the need, but as far as we know, no such program exists for cognitive

systems engineering. There is, of course, a large amount of literature, but little of it provides a gentle introduction and much of it offers competing claims.

We saw the possibility that a one-day workshop could fill a need by framing the issues and instructing in straightforward techniques that flowed from knowledge elicitation through knowledge representation into design and then into evaluation.

Our main goal was to provide a form of experience in which participants would develop a good level of comfort with some basic methods and acquire a comprehensive perspective of the CSE enterprise. Given the constraint that this had to be done within a working day, we believed we should focus on a small set of tools with an intuitively plausible rationale and a framework that would establish a context.

Decision Centered Design as supported by the critical decision method and the decision requirements table satisfied that constraint and fulfilled the requirement of progressing through the complete sequence of knowledge elicitation, knowledge representation and design. The addition of the material on cognitive indicators completed the sequence through the evaluation stage. The material on macrocognition provided the comprehensive framework that would allow workshop participants to view these tools as an integrated suite.

In presenting this material, we noted other frameworks but avoided any evaluative judgment regarding relative effectiveness within the cognitive systems engineering enterprise. Additionally, we kept away from arguments about effectiveness of cognitive systems engineering, assuming that those in attendance would already be favorably inclined, and we minimized theoretical discussion in the belief that this workshop would be successful if it were focused on the development of self-sustaining level of skill with basic tools.



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Table 1. Example message injects for Information Management exercise.

<b>To/From, Time</b>	<b>Subject</b>	<b>Message</b>
<b>00:00</b> <b>To: Sunray, From 1<sup>st</sup></b> <b>Platoon</b>	Spot Report	1 <sup>st</sup> Platoon relocated to A2
<b>00:00</b> <b>To: Sunray, From 2<sup>nd</sup></b> <b>Platoon</b>	Spot Report	2 <sup>nd</sup> Platoon relocated to A3
<b>00:00</b> <b>To: Sunray, From Hawk</b>	Spot Report	Hawk reports 2 unknowns in D4
<b>03:00</b> <b>To: Sunray, From</b> <b>DIVMAIN</b>	Movement	AUTOMATED MESSAGE: Sensors detect movement

## Figure Captions

Figure 1: CSE project for workshop participants

Figure 2. Map provided to Information Management exercise participants.

Figure 3: Job aid for the Critical Decision method

Figure 4: Macrocognition as a framework for CSE

Figure 5: Decision requirements table for analyzing qualitative data

Figure 6: Cognitive Performance Indicators