Concept Maps: Theory, Methodology, Technology
Proc. of the First Int. Conference on Concept Mapping
A. J. Cañas, J. D. Novak, F. M. González, Eds.
Pamplona, Spain 2004

EXPANDING CONCEPT MAPPING TO ADDRESS SPATIO-TEMPORAL DIMENSIONALITY

Isaac Brewer & Michael McNeese
The Pennsylvania State University
University Park, PA

Abstract. Concept mapping has been used in multiple research domains for a variety of purposes such as brainstorming, knowledge elicitation, student testing and evaluation. Our work has applied the technique with pilots, emergency managers, emergency responders, and image analysts. Indeed, concept mapping has proven to be valuable both as an end state to represent and in turn understand knowledge, as well as the means to acquire knowledge from experts or users. This paper explores one path in the history of concept mapping use as a knowledge elicitation device, emphasizing its application in frameworks of knowledge acquisition. We conclude with proposed perturbations that help researchers account for spatio-temporal factors in task and event elicitation.

1 Introduction

Concept mapping has emerged from varied backgrounds and influences (e.g., cognitive science, learning and instruction) while being put to use for multiple purposes (e.g., brainstorming tool, knowledge elicitation, student testing and evaluation). Indeed, concept mapping has proven to be valuable both as an end state to represent and in turn understand knowledge, as well as the means to acquire knowledge from experts or users. Our own use of concept mapping (historical and current) derives from the AKADAM (Advanced Knowledge And Design Acquisition Techniques, McNeese et al., 1990; Zaff, Snyder, & McNeese, 1993); AKADAM was devised for user-centered knowledge elicitation in support of participatory design (McNeese et al. 1995). AKADAM utilized scenario-building, concept mapping, IDEF functional decomposition, and design storyboarding techniques as an integrated bundle to promote synthesis of reconfigurable prototypes and technology that emphasis cognition acting in context. Over the last 15 years, we have adapted AKADAM techniques (e.g., concept mapping used with storyboarding and video-taping) to respond to various demands inherent in work situations. An example of this is that we started working more consistently with teams and in turn developed CM as an active group technique for eliciting and representing models of how groups formulated and used knowledge in a given context (McNeese et al., 1992). From this initial conceptualization of concept mapping within the AKADAM framework, several complementary strains also developed and matured. Our particular research (distilled from AKADAM) has focused on the mutual interplay of understanding, modeling, and measuring individual / team cognition within complex systems. This can be achieved when several representations and uses are exploited through integrated methods and tools. Specifically, the application of *cognitive engineering techniques* (McNeese et al. 1995; McNeese 2002), *cognitive field research tools* (Sanderson et al. 1994; McNeese et al. 1999), *cognitive modeling methods* (Perusich & McNeese 1997; Perusich, McNeese, & Rentsch, 1999), *scaled world simulations* (McNeese et al. 1999; McNeese, 2003), and *team schema similarity measurement* (Rentsch et al. 1998; McNeese & Rentsch 2001) have all played together as a coherent nexus of research activity. Our latest comprehensive view – the Living Lab Approach (McNeese, in press) – actively utilizes four major components (field research, knowledge elicitation, scaled world simulations, and reconfigurable prototype designs) to develop theory, knowledge, models, and interventions of use. The Living Lab facilitates the latest use of concept mapping with the intention to connect concept maps within this larger perspective of integrated research. Earlier techniques in concept mapping (McNeese, Zaff, & Snyder, 1993) primarily reflected access of declarative and (to a certain extent) and procedural memory. Our current work in concept mapping is designed to reflect processes more attuned to situation cognition (e.g., reflecting episodic and eidetic memories, temporal patterns and conflict, and the invariants that constrain action in contexts). In turn, the paper looks at historical markers in AKADAM but puts forth some of our new directions in temporal-based concept mapping.

The objective of this paper is to review use of concept mapping in the AKADAM framework from past to current uses; and to suggest some new perturbations based on what has been discovered over the past 15 years. The goal is to establish some new directions and adaptations given previous use of the techniques. Certainly, AKADAM represents only a limited view of the grand terrain of concept mapping. Other authors and schools of thought provide both similar (e.g., Klein, et al., 1993; Gaines & Shaw, 1992; Gordon, Scmierer, & Gill, 1993; Hoffman, Crandall, & Shadbolt, 1998) and different ideas and cases on how concept mapping provides value and use. One more point – as we scale the terrain of concept mapping – the particular lens that allows us to see the wide angle of what we are doing is that of cognitive systems engineering and design (e.g. Hollnagel & Woods, 1983; Rasmussen et al, 1994; Sanderson, McNeese, & Zaff, 1998; Woods, 1998).

2 Basic Foundations

Much of our approach that lies behind concept mapping is tied to agent-environment transactions wherein cognition and context are both considered valuable components of *experience*, mutually influencing each other (see Young and McNeese, 1995). The approach we have utilized emphasizes both cognition and context. In turn, the theoretical foundation for our work lies within what other authors have referred to as situated cognition (Brown, Duguid, & Collins, 1989), distributed cognition (Hutchins, 1995), plans and situated actions (Suchman, 1987), socially shared cognition (Resnick, 1991). This is best captured by the statement, "What is inside your head is a reflection of what your head is inside of" (adapted from Mace, 1977). This provides justification for both the mental models (Johnson-Laird, 1983) that encode experience for future use and expectations, the prominent role of perception in experience, as well as the ecological context that offers affordances and effectivities for an agent. This is not unlike other approaches that Rasmussen, Flach, Klein, Woods, and Vicente (see Eggleston, 2003) have elucidated within the general purview of cognitive systems engineering. All of these approaches give credence to the role of context and environment and even social environment – but some give the role of context a greater emphasis therein invoking a greater ecological emphasis.

In our early work (McNeese et al. 1990) the intent was to use the concept map (1) as a means to facilitate user-centered, participatory knowledge elicitation that would allow users to spontaneously access knowledge and capture that knowledge visually as concepts, what we then referred to as *knowledge as concepts* (2) to include within the knowledge capture and representation of the behavioral-shaping constraints (Rasmussen, Petjersen, & Goodstein, 1994) that the context brought strongly within situations (3) to translate the captured knowledge into designs or tools (McNeese et al. 1995), termed *knowledge as design.* In summary, our approach is based on capturing specific cognition in context using concept mapping procedures and then representing an external mental model as variant forms of concept maps (e.g., definitional, procedural, fuzzy).

3 Procedures Related to First Principles

The basic foundation of our CM procedures was predicated on two theoretical first principles: *spontaneous access of knowledge* (Bransford & Stein, 1993) and *ecological contextualism* (Hoffman & Nead, 1983). The first principle focused on the cognitive processes inherent in having a user heed or explain "the things" that influenced their behavior (for a given problem or domain of interest). When people spontaneously access their knowledge (without being told to do so), it is an indication that knowledge has been integrated and put to use for specific situations and, in turn, is salient in their memory. To bring this idea out as part of our procedures, we would begin with an expert (or group of experts) being asked to develop a choice scenario. The scenario would be contingent on recalling their own experiences (stories, critical incidents, routines, memorable occasions) with potential focus on a specific problem that the expert encountered in their own work. This scenario then provides a basic-level timeline which can be used later on in more temporal aspects of the procedure. After they have worked together on the scenario (we prefer this if we have more than one expert working at a given session as it gives an initial cross-validation), they begin to develop (with the concept mapper) a *concept definition map*. In older terminology, a definition map would contain what has been referred to as declarative knowledge, but it contains declarative knowledge in a semantic-web like structure that is inclusive of contextual information that influences activities on the part of the user. These definition maps are initiated by the mapper through the use a of a mid-range probe to jump-start the process. The scenario itself and the probe can be thought of as "cognitive anchors" that facilitate problem-based learning processes which emphasize the social construction of knowledge. As the map continues, there are opportunities for the "knowledge board" to ask additional apropos probe questions as well which are mapped into the closest related concept cluster.

The goal has been to create an environment for knowledge elicitation that facilitates active and spontaneous access of knowledge (without being told), Bransford, Sherwood, Hasselbring, Kinzer, & Williams (1992). This type of knowledge – when elicited – shows condition-action pairings that have been bound and remembered with respect to actual problem states, challenges, or difficult bottlenecks a person has encountered. Once a person starts to "generate knowledge" it typically pulls out a natural neurologically-based cluster of related concepts that are mapped on whiteboards or large sheets of paper for the mappee to "see". As the map begins to form, it substantiates the idea of a perceptual anchor (McNeese, 2000) consisting of *knowledge as concepts* (McNeese et al. 1990). We have referred to this process as "see what you think" or one that externalizes a person's mental model. However, the hope is that the concepts within a person's mental model will be grounded in situated events and therein elicit insights about the context (e.g., the behavioral shaping constraints). When ecological etchings are compacted into a concept map, one obtains what we have referred to as an "ecography" (Zaff, McNeese, & Snyder, 1993). So our view of CM is that you have a "mapping agent" visually represent in front of you “the things” that you use to identify and solve problems. This first mapping then typically deals with things that are not really temporal or procedural but is driven more by problems, definitions, connections and associations that a person heeds given their belief system about x^n.

The concept definition map is fine for front-end work in cognitive task analysis and in fact may be used to propagate other more sophisticated cognitive structures such as abstraction hierarchies (Rasmussen et al 1994), human performance models (Bautsch & McNeese, , 1997), in addition to design storyboards. However, one of the limitations we discovered is the necessity for associating specific knowledge with temporal sequences. In turn, the procedural concept map was created to connect clusters of knowledge with a sequence of procedural steps or temporal timeline of events (McNeese et al 1990). This method also provided a segue into the design storyboard technique as design storyboards emerge via a scene that progresses over time “frame-by-frame”. Therein, in addition to definition maps we added procedural-based maps to our repertoire to capture concepts related to a sequence of events. Note that this bridge between concepts and storyboard frames (across time) also intersected another component of our techniques: the scenario/script. When we had experts create a scenario, they socially constructed knowledge about a scene around a problem or critical incident that emerged over time (i.e., it is laid across a time sequence with a given unit of measurement, e.g.,minutes). The procedural concept map addressed some limitations of the definitional map as it provided a means to address issues that focused on temporality, event sequences, and an emerging problem space that created a trajectory into the future. One limitation, however, was that most of our procedural maps tended to be linearly sequential and therein rigid and inflexible to other forms of temporality and sequence (non-linearity, chaotic, timing patterns coupled to recurrent events).

4 Current Applications and Interests

The application of AKADAM to various real world domains has spanned across design teams, fighter pilots, command and control operations, helicopter operations, etc. (see McNeese et al 1995). However, our current operations tend to center more on homeland security concerns (emergency crisis management, image analyst operations, intelligence analyst operations, dispatch centers). We now view AKADAM as residing within part of the general Living Laboratory Perspective, as mentioned earlier, (McNeese, 1996; McNeese, Perusich, & Rentsch, 2000; McNeese, in press) for conducting cognitive systems engineering. The focus for the rest of this paper is centralized on the operational domain of hurricane crisis management (Brewer, 2004) and how concept mapping is currently evolving for this domain use.

Temporal events are critical in emergency response activities for all types of crises and disasters. Concept mapping sessions using mission scenarios were conducted with emergency managers in South Carolina and Florida. These concept mapping sessions were aimed at eliciting the task structures employed by emergency managers, while also building up a concept definition map of the types of information and activities involved within their work. A general overview about the knowledge elicitation procedure appears in Brewer (2002). Related to this study, the research centered upon eliciting expert knowledge about the process of preparation, preparedness, response and immediate recovery by state and county level emergency operations centers when a hurricane made landfall in the state. Teams of emergency managers were led through the same scenario so that comparisons of collaboration between team members, and identification of differences within job responsibilities could be compared. The linear concept map was based on the previous work done for AKADAM with pilots. A noted difference that has led to extensions of the approach involves the temporal scale at which the two types of linear concept maps were created.

In the case of the pilots, a linear scale was highly appropriate because it included only a short time window for task completion (from the time a pilot noticed a threat until it acquired the target within his targeting system). This time span was on the order of seconds to minutes. In the case of linear temporal concept mapping, with emergency mangers responding to a hurricane, the time line stretched from the beginning of hurricane season (early June) and narrowed to time span from 72 hours before landfall until 24 – 72 hours after landfall. The longer time span increased the opportunities for variance and external forces to enter into the crisis situation, fundamentally changing the nature, type and duration of the emergency manger’s tasks. This recognized limitation in a solely linear based concept mapping activity led us to rethink the methodological approach and offer forth alternative suggestions for how concept mapping can be used as a knowledge elicitation technique for temporal tasks and scenarios. We still believe that for short tasks that occur within a relatively short timeframe, that linear concept mapping might be most appropriate, but for larger scale events and tasks, other approaches could potentially yield more accurate results. A proposed typology is highlighted in the next section.

5 Progressing Towards the Future

Time is an element that is ever-present in all human activities. Unfortunately, temporal components are often omitted from characterizations of activities and events because of the difficulty in its representation. Within knowledge elicitation activities, by focusing on time directly, we have the opportunity to improve our understanding of not only the nature of time, but also in the influence it has on human activities. Below (Figure 1) we outline a first pass at classifying temporal activities for the purposes of eliciting expertise on tasks and scenarios.

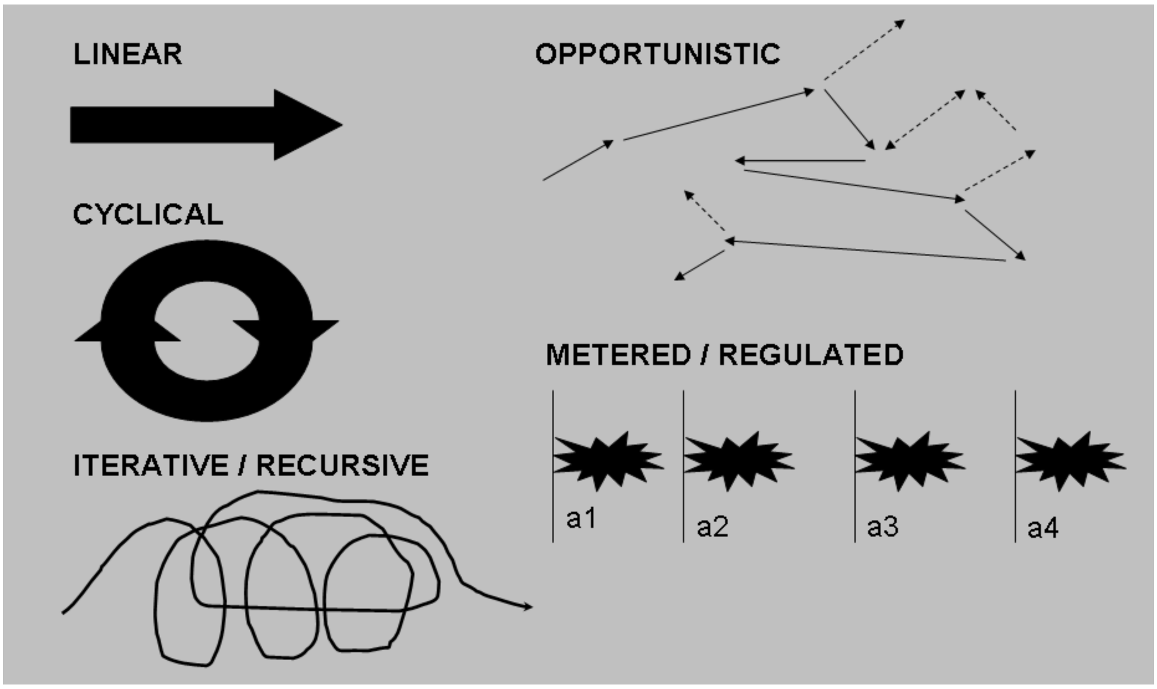

Figure 1: Preliminary Typology of Temporal Intervals

For each of the representations of temporal activities above, the lines represent the person doing the task required. Each line is then propagated with concept maps related to the temporal component. For example, in the linear concept map, time can be captured on a concept maps as events which occur before another event, yet the duration of time in between events has no representation (figure 2).

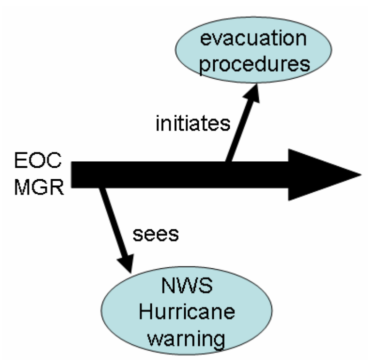

Figure 2: Simple Propagation Example

For linear temporal maps, the tasks should have short durations. An example of an appropriate task for using linear concept mapping would be analyses of gestures between two individuals for communication, human computer interaction research of mouse and keyboard inputs, etc. Cyclical time would be for activities with a range of temporal duration. It would be appropriate for eliciting knowledge from scientists or weather forecasters who deal with seasonal changes, diurnal changes, El Nino cycles, tidal influence, or lunar events. Iterative or recursive time could be used for analyses of software designers, engineers, industry experts, or scientists conducting experiments. Opportunistic temporal concept mapping would be appropriate for decision making tasks that have a lot of if/then variables and or paths of least resistance. Examples could include medical diagnoses, court proceedings, or economic patterns. Finally, the last type, metered or regulated involves temporal situations where an activity happens with direct repercussions until another event occurs which completely ends the first event and creates a new event. The numbered items are the 'anchor points' discussed previously. Eliciting knowledge via scenarios of work would be appropriate for this method, as would eliciting knowledge from actors, musicians, or movie-makers. This first pass at different temporal anchoring schemes for knowledge elicitation is, by nature, transitional. Like all things, it has room to evolve and develop over time.

These schemes then highlight more of the procedural and episodic components of memory, emphasizing how specific temporal knowledge patterns are inherent in the fabric of work settings. When these temporal patterns are coupled to the more traditional forms of concept mapping that emphasize the declarative contents of knowledge, a more comprehensive understanding of cognition in context can emerge. This is what we have discovered in the hurricane management center research. In turn, this more broader understanding can be used to leverage more veridical models of teamwork while enhancing the effectiveness of envisioned designs.

In conclusion we have looked at a variety of concept mapping ideations and schemes, focusing on differing ways concept maps have been used and adapted for unique situations. Inherently, the issues surrounding episodic events and the temporal patterns of work have driven innovative forms of concept mapping that extend the AKADAM techniques in new ways. This has been demonstrated for one of our domain applications in homeland security, hurricane crisis management.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No.BCS-0113030 and Grant No. EIA 0306845 and partially supported by an Office of Naval Research, Division of Cognitive Science, Collaborative and Knowledge Management Program Grant, Dr. Michael Letsky, Program Manager (Grant no. N00140210570).

References

Bransford, J. D., Sherwood, R. D., Hasselbring, T. S., Kinzer, C. K., and Williams, S. M. (1990). Anchored instruction: Why we need it and how technology can help. In D. Nix and R. Spiro (Eds.), *Cognition, education, and multimedia: Exploring ideas in high technology* (pp. 115-141). Hillsdale, NJ: Lawrence Erlbaum.

Bransford, J. D., & Stein, B. S. (1993). The ideal problem solver: A guide for improving thinking, learning, and creativity (2nd edition). NY: Freeman & Co.

Brewer, I. 2002. Cognitive Systems Engineering and GIScience: Lessons Learned from a Work Domain Analysis for the Design of a Collaborative, Multimodal Emergency Management GIS. GIScience 2002, Boulder, CO. Sept 25-28, 2002.

Brewer, I. 2004. Understanding the Use of Geospatial Information and Technologies in Crisis Management Department of Geography, The Pennsylvania State University.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*, 32-42.

Eggleston, R. G. (2002) Cognitive systems engineering at 20-something: Where do we stand? In M. D.,McNeese & M. A. Vidulich (Eds), *Cognitive systems engineering in military aviation environments: avoiding cogminutia fragmentosa* (pp. 15-78). Wright-Patterson Air Force Base, OH: Human Systems Information Analysis Center.

Gaines, B.R. and Shaw, M.L.G. (1992b). Integrated knowledge acquisition architectures. *Journal for Intelligent Information Systems*, *1*(1) 9-34.

Gordon, S.E., Schmierer, K. A., & Gill, R. T. Conceptual graph analysis: Knowledge acquisition for instructional system design. *Human Factors*, *35*(3), 459-481.

Hoffman, R. R., Crandall, B., & Shadbolt, N. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. *Human Factors*, *40*(2), 254-276.

Hoffman, R. R., & Nead, J. M. (1983). General contextualism, ecological science and cognitive research. *The Journal of Mind and Behavior*, *4*(4), 507–559.

Hollnagel E., & Woods D. D. (1983) Cognitive systems engineering: New wine in new bottles. *International Journal of Man-Machine Studies*, 18, 583-600.

Hutchins, E. (1995). *Cognition in the wild.* Cambridge, MA: MIT Press.

Johnson-Laird, P. N. (1983). Mental models: towards a cognitive science of language, inference, and consciousness. Cambridge, MA: Harvard University Press.

Mace, W. M. (1977). James J. Gibson''s strategy for perceiving: Ask not what 's inside your head but what's your head is inside of.. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing* (pp. 43-65). Hillsdale, NJ: Erlbaum.

McNeese, M. D . (1996) . An ecological perspective applied to multi-operator systems. In O. Brown & H. .L Hendrick (Eds.) *Human factors in organizational design and management - vi*. (pp. 365-370). The Netherlands: Elsevier.

McNeese, M. D. (2000). Socio-cognitive factors in the acquisition and transfer of knowledge. *International Journal of Cognition, Technology, and Work, 2,* 164-177.

McNeese, M. D. (2002) Discovering how cognitive systems should be engineered for aviation domains: A developmental look at work, research, and practice. In MD McNeese, & MA Vidulich (Eds.), *Cognitive systems engineering in military aviation environments: Avoiding cogminutia fragmentosa* (pp. 79-119). Wright-Patterson Air Force Base, OH: Human Systems Information Analysis Center.

McNeese, M. D. (2003). Metaphors and paradigms of team cognition: A twenty year perspective, *Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society* (pp. 518-522). Santa Monica: Human Factors and Ergonomics Society.

McNeese, M. D. (in press). How video informs cognitive systems engineering: Making experience count," *International Journal of Cognition, Technology, and Work.*

McNeese, M. D., Bautsch H., & Narayanan S. (1999) A framework for cognitive field studies. *International Journal of Cognitive Ergonomics*, *3*(4), 307-331.

McNeese, M. D., Perusich, K., & Rentsch, J. R. (1999). What is command and control coming to? Examining socio-cognitive mediators that expand the common ground of teamwork. *Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomic Society* (pp.209-212). Santa Monica, CA: Human Factors and Ergonomics Society.

McNeese, M. D., Perusich K., & Rentsch J. R. (2000) Advancing socio-technical systems design via the living laboratory. *Proceedings of the Industrial Ergonomics Association / Human Factors and Ergonomics Society*(IEA/HFES) *2000 Congress* (pp. 2-610 – 2-613), Santa Monica, CA: Human Factors and Ergonomics Society.

McNeese, M. D., & Rentsch, J. R. (2001). Identifying the social and cognitive requirements of teamwork using collaborating task analysis. In M. D. McNeese, E. Salas, & M. Endsley (Eds). *New trends in collaborative activities: System dynamics in complex environments* (96-113). Santa Monica, CA: Human Factors and Ergonomics Society Press.

McNeese, M. D., Zaff, B. S., Brown, C. E, Citera, M., & Wellens, A. R. (1992). The role of a group-centered approach in the development of computer-supported collaborative design technologies. *Proceedings of the 36th Annual Meeting of the Human Factors Society* (pp. 867-871), Santa Monica, CA: Human Factors Society,

McNeese, M. D., Zaff, B. S., Citera, M., Brown, C. E., & Whitaker, R. (1995). AKADAM: Eliciting user knowledge to support participatory ergonomics. *The International Journal of Industrial Ergonomics*, *15* (5), 345-363.

McNeese, M. D., Zaff, B. S., Peio, K. J., Snyder, D. E., Duncan, J. C., & McFarren, M. R. (1990). An advanced knowledge and design acquisition methodology: and application for the pilot’s associate (AAMRL-TR-90-060). Wright-Patterson Air Force Base, OH. Armstrong Aerospace Medical Research Laboratory.

Perusich, K., & McNeese, M. D. (1997). Using fuzzy cognitive maps to define the search space in problem solving. In G. Salvendy, M. Smith, & R. Koubek (Eds.), *Design of Computing Systems: Cognitive Considerations.* (pp. 805-809). Amsterdam, The Netherlands: Elsevier Science Publ. B.V.

Perusich, K., McNeese, M. D., & Rentsch, J. (1999). Qualitative modeling of complex systems for cognitive engineering. In *Proceedings of the SPIE* (Alex F. Sisti, Ed.), *Vol. 3996,* 240-249.

Rasmussen, J., Pejtersen, A. M., Goodstein, L. P. (1994). *Cognitive engineering: Concepts and applications*. New York: Wiley.

Rentsch, J. R., McNeese, M. D., Pape, L. J., Burnett, D. D., Menard, D. M., & Anesgart, M. (1998). Testing the effects of team processes on team member schema similarity and task performance: Examination of the team member schema similarity model. AFRL-TR-98-0070. Wright-Patterson Air Force Base, OH: Air Force Research Laboratory.

Resnick, L. B. (1991). Shared cognition: Thinking as social practice. In L. B.Resnick, J. M. Levine, & S. D. Teasley (Eds), *Perspectives on socially shared cognition.* Washington DC: APA Books.

Sanderson, P. M., McNeese, M. D., & Zaff, B. S. (1994). Handling complex real world problems with two cognitive engineering tools: COGENT and MacSHAPA. *Behavior Research Methods, Instruments, & Computers*, *17* (2), 117-124.

Suchman, L. A. (1987). Plans and situated actions - The problem of human-machine communication. New York: Cambridge University Press.

Vicente, K. J. (1999). *Cognitive work analysis*. Mahwah, NJ: Erlbaum.

Woods, D. D. (1998). Designs are hypotheses about how artifacts shape cognition and collaboration. *Ergonomics*, *41*,168-173.

Young, M. F., & McNeese, M. D. (1995). A situated cognition approach to problem solving. In P. Hancock, J. Flach, J. Caird, & K. Vincente (Eds.), *Local applications of the ecological approach to human-machine systems*. Hillsdale, NJ: Erlbaum.

Zaff, B. S., McNeese, M. D., Snyder, D.E. (1993) Capturing multiple perspectives: A user-centered approach to knowledge acquisition. *Knowledge Acquisition*, *5*(1), 79-116.