Concept Maps: Theory, Methodology, Technology
Proc. of the Second Int. Conference on Concept Mapping
A. J. Cañas, J. D. Novak, Eds.
San José, Costa Rica, 2006

IN THE HEAT OF THE MOMENT . . . STRATEGIES, TACTICS, AND LESSONS LEARNED REGARDING INTERACTIVE KNOWLEDGE MODELING WITH CONCEPT MAPS

John W. Coffey, Department of Computer Science,
The University of West Florida & The Florida Institute for Human and Machine Cognition
Pensacola, FL, USA
Email: jcoffey@uwf.edu

Abstract. The intent of the article is to provide experience-based, basic, practical observations regarding expert knowledge elicitation with concept maps. This article contains a description of techniques for the interactive, collaborative construction of concept maps by a domain expert and a facilitator (who is typically not a domain expert) and the selection or creation of accompanying resources. After a brief review of relevant literature, this article provides a description of the value of and approaches to advance preparations for concept mapping sessions, strategies and tactics that help sessions to get off to a good start, the process of creating hierarchical organizations of concept maps, making decisions regarding what to capture in concept maps and what to capture by accompanying resources, and the refinement and verification of knowledge models.

1 Introduction

Concept maps have proven useful for the elicitation and representation of expert knowledge. Knowledge elicitation methods using concept maps encompass a range that includes use of pencil and paper or electronic concept mapping tools, interactive approaches, and those in which maps are created off-line from inputs obtained by other means. In some instances, experts create their own concept maps. More often, one or more facilitators who are skilled at knowledge elicitation (KE) but not necessarily expert in the knowledge domain help one or more experts create the concept maps. Interactive, facilitated methods have become the norm at the Florida Institute for Human and Machine Cognition (IHMC). Such sessions are frequently extremely fast-paced, and some basic rules of thumb might improve the results.

The rest of this paper presents a description of some of the lessons the author has learned in 16 years of concept mapping for KE. Following a brief literature review, this article identifies issues pertaining to preparation for the sessions, concerns that arise in the initial sessions such as how to avoid eliciting superficial, well-known knowledge, ways to generate and use focus questions, how to use parking lots, sub-maps and placeholder maps, when to stop mapping and use other electronic resources, what to do when the elicitors seem to be missing a lot of the proceedings, and a few examples of alternative representations to concept maps that might be more suited to the capture of particular types of knowledge. The paper concludes with a summary of the points made. The next section provides a brief overview of literature pertaining to knowledge elicitation and modeling with Concept maps.

2 Knowledge Elicitation and Modeling using Concept Maps

The following brief literature summary provides background for this article. Since Novak and Gowin (1984) originally defined Concept Mapping as a means to externalize science student understandings and misapprehensions, Concept Mapping has proven useful for knowledge elicitation (KE) and knowledge modeling (Ford, et al., 1991; Ford, Cañas, & Coffey, 1993). This early literature on the subject described a concept map as a "mediating representation," an explicit knowledge representation that serves as an intermediary between an expert and a knowledge elicitor in efforts to externalize conceptual knowledge and create meanings. The elicited Concept Maps have been used to structure what have been termed "knowledge models," hierarchically structured groups of concept maps that are linked together and augmented with other electronic media.

Hoffman, Shadbolt, Burton, and Klein (1995) described various types of KE methods including what they termed "contrived" techniques. This category includes the creation of diagrammatic representations of knowledge in the form of linked networks of concepts or Concept Maps. Hoffman et al characterized concept map creation as a contrived technique because elicitation of concept maps does not entail the expert actually performing tasks from his or her usual repertoire of capabilities. The fact that concept mapping is a contrived technique suggests that

augmenting concept maps with other appropriate media to foster greater understanding, a process called knowledge modeling at IHMC, might bear special consideration.

McNeese and colleagues (McNeese et al. 1993; McNeese et al. 1995) were early adopters of concept mapping techniques to create external representations of knowledge that is being communicated. Studies they cited involved the elicitation of maps with a variety of experts including pilots and design teams. More recent work (Brewer & McNeese, 2004) has involved knowledge elicitation with concept maps in service of elucidating emergency response task structures, and the types of information and activities involved in emergency response work. Their newest work addresses strategies to introduce a temporal dimension into the knowledge elicited in order to capture what the authors characterize as "episodic events and temporal patterns."

Novak (1998) described knowledge elicitation as a means of idea generation in groups of people. Novak described working with large groups of people who were sub-divided into smaller groups that built maps, and then re-convened in the larger group to share results. Dumestre (2004) described interactive concept mapping in service of job-task analysis in the Navy. Sessions involved large groups of experts (17 in one group, 18 in the other) with a single moderator and recorder in each group. Dumestre concluded that it was more time efficient to gain group consensus with interactive concept mapping than with traditional note-taking and summarizing.

Concept Maps have been used in institutional memory preservation work. In work at NASA Glenn Research Center (Coffey, 1999), Concept Maps were used in order to capture, represent, and preserve institutional memory of senior scientists on issues pertaining to launch vehicle systems integration. The Centaur upper stage and the RL-10 engine were chosen for detailed analysis in this study. Coffey & Hoffman (2002) described a knowledge elicitation cycle involving an initial preparation phase with an iterative process of determining scope, eliciting, rendering and verifying. The result of the effort was a knowledge model organized around Concept Maps. Coffey, Eskridge, and Sanchez (2004) described interactive concept map creation as a knowledge elicitation scheme for memory preservation work at a nuclear power plant. In this work, the idea of activity maps emerged. Activity maps are useful for the elicitation and representation of the types of activities an expert engages in, and have proven valuable in gaining insight in what experts actually do. That study also demonstrated that it is possible when working with experts to produce at least one rich concept map per hour over an extended period of time (a week or more).

The literature described in this review illustrates a range of methods and goals for which interactive concept map-based knowledge elicitation might be employed. The goal of such work might be to foster idea generation or group consensus pertaining to a domain of knowledge, or it might be to capture uniquely held, idiosyncratic knowledge of an expert. Overlapping but occasionally divergent concerns pertain to the pursuit of these and other goals for concept map-based knowledge elicitation. The remainder of this paper will attempt to enumerate generally applicable principles pertaining to all types of knowledge elicitation with concept maps.

3 Preparing for the Sessions

Experience has shown that if the knowledge elicitors are not domain experts, every bit of advance preparation that is possible makes a positive contribution to the outcome of the work. This is particularly so in sessions aimed at eliciting knowledge from individual experts. It has become just as evident that no two preparations for knowledge elicitation sessions unfold in the same manner or achieve the same results. One of the main benefits of significant advance preparation is the possibility of quickly getting past the foundational knowledge in the domain and into a depth of understanding that might be of use to other experts. The remainder of this section addresses these points.

3.1 You cannot know too much going in

There are two compelling reasons why a knowledge elicitor must know absolutely as much as possible about the knowledge domain under consideration before starting:

- A fundamental issue in successful knowledge elicitation is establishing credibility with the expert. One of the best ways to do this initially is to be conversant in the basic issues the expert deals with.
- Basic efficiency is a separate concern. Experts typically live with significant time pressure. It is unacceptable to attempt to learn the basics of the knowledge domain on the expert's time.

The preparation phase may take on different forms depending on the knowledge domain, the availability and format of background materials, etc. The last several projects in which the author has been involved have addressed ascent guidance for the space shuttle, differential thermo-structural loads and stresses that impact assembly or reconfiguration of the international space station, and the operation of the turbine system in a nuclear power plant. Preparation for the first two of these undertakings was made from papers written by the experts. Since the papers were seminal in the respective fields and described the experts' core work, it was possible to attain a relatively clear understanding of what would be discussed in the sessions and the basic vernacular of the knowledge domain as the experts used it.

Preparing for work with the turbine engineer was completely different. He was a line worker who kept machines running and did not write papers about his techniques as a matter of course. The employing organization had established a program to preserve institutional memory, of which this work was a part. Part of this program was an initiative to collect information regarding what each of the plant's employees knew and did, and the criticality of their work to the overall operation. The summaries were brief, high-level, and in some cases contained errors. Nevertheless, a list of questions that was generated regarding terms used in the summaries, and additional information such as the number and types of people who worked for the expert, yielded some useful background. This information was noticeably different in quality and quantity from resources used to prepare for the other two previously cited activities.

Another element of preparation that can be highly effective is to build one or more concept maps or a complete rudimentary knowledge model of the introductory materials as part of preparation. This model can be reviewed with the expert early in the process to determine accuracy and to fix mistakes, to identify focus questions (which are described in the next section), and to establish rapport. Additionally, showing and reviewing such a knowledge model helps the expert to understand what will be produced by the sessions. Experts are humans and therefore generally not displeased to find that the elicitor is studying their work. In these circumstances, the mapping process plays the same role as it did in Novak's original conception - it allows the expert and the elicitor to identify very quickly any incorrect notions the elicitor constructed as part of the preparation process. Additionally, as described in the next section, such efforts facilitate starting work with the expert at a greater depth than might otherwise be possible.

3.2 Avoiding "knowledge domain 101"

For efficiency, it is important to start elicitation at significantly greater depth than the basics of the knowledge domain. With careful advance preparation specifically geared to the expert's areas of expertise, it is possible to create at least a sketchy overview of what the expert knows before actual knowledge elicitation begins. This is the best possible situation because it can lead to a dialog in which an assessment can be made regarding areas that are generally well documented or known, (and hence, of less interest) and those that might be uniquely or idiosyncratically understood by the expert.

Examination of the concept maps created as part of the preparation process can be a highly useful factor in formulating an initial set of focus questions. By their very nature, these questions should be significantly more focused than a very general approach that starts with "tell me what you know about X." Novak (1998) describes a case in which concept mapping was used to formulate research questions for a doctoral dissertation by building and examining a concept map of the knowledge domain. A total of 6 research questions were identified by posing questions regarding what the possible relationships might be between concepts that were not linked together, but that were thought to have some connection. A similar approach applied to concept maps that were developed as part of the preparation phase could yield an initial group of deep, meaningful focus questions that might be refined before sessions start, or as a first activity with the expert when actual work commences.

4 The Initial Rounds of Knowledge Elicitation

This section addresses issues that arise when getting started. The personnel who manage the project can be expected to inform the expert regarding the goals of the work. However, the expert must be helped to understand what will transpire in the sessions and why the process is carried out as it is. A briefing regarding the goals of the work, accompanied with a review of preliminary concept maps, can help the expert to gain this understanding. This section

describes other concerns including how to use focus questions, bottom-up versus top-down initial efforts, getting an early focus on the emerging concept map, and some heuristics regarding structuring of the model into more detailed concept maps.

4.1 Using focus questions

It is critically important to start with a best-guess focus question to define the goal of the initial session. It might be possible to identify a number of focus questions before sessions start. However, it must be recognized that the initial set of questions might not encompass the range of items of interest that emerge in the sessions. It is also not uncommon for the proceedings to drift off the initial question - an element of opportunism and exploration are always present in the early part of such work. As the session unfolds and more concepts are elicited, a judgment must be made if a different topic is emerging or if the current direction leads to a better articulation of the original focus question with a different emphasis. The session might lead to a modification of the focus question or the identification of a different topic to be explored later. It is a common practice to make placeholder maps - concept maps that hold a question or a few concepts of interest for future consideration.

4.2 Parking lots to Start

It is practically always a good idea to start by writing down a number of concepts and making only minimal efforts to link them together initially. It is easy to arrange them into clusters on the page if such groupings are evident. On the other hand, with a very rapid-pace expert, a great many concepts might accumulate very quickly. If this happens, it is quite likely that some of the concepts may be at a different level of detail (described as granularity) than others, and some may not be relevant to the current topic. Some of the items that are less closely related might be placed in another concept map with a focus question pertaining to the new map. This type of activity is in the general realm of creating sub-maps or placeholder maps, the topic of the next section. Novak's heuristic of approximately 10-12 concepts in a parking lot is reasonable for on-the-fly knowledge elicitation, although rapid-fire sessions can quickly lead to the identification of many more than this. It is necessary to work on linking items together sooner or later, and carrying out the linking process is a good time to get attention focused on the map itself. By referring the expert to the map and explicitly asking for the relationship between two concepts, the focus can be placed on the mediating representation, the topic of the next section.

4.3 Get the focus on the Concept Map

The generally accepted method of knowledge elicitation advocated by the IHMC is a two-person team with one member designated as the moderator and the second member the recorder (Coffey et al. 2003). The role of the moderator is to interact with the expert to keep the conversation moving and on-topic, and to ensure that the recorder is keeping up with the discourse. The recorder actually creates the concept map as the discussion unfolds. The recorder's job is complex; it is not akin to that of a court stenographer since the recorder has to make ongoing decisions regarding the arrangement of items in the map, potential connections between items, when to create sub-maps (see the next section), etc.

Extensive experience with interactive mapping has shown that it is very easy (at least initially) to fall into a process in which the moderator and expert talk back and forth, generally ignoring the emerging representation of the conversation that the recorder is producing, as the recorder struggles to keep up with the flow of ideas. Without a concerted effort to avoid this problem, it is easy for the expert and moderator to lose track of how the recorder is keeping up and, in such situations, important knowledge might be lost. This problem can be avoided by quickly establishing a focus on the concept map. The sooner the focus of the conversation is directed to the construction of a concept map, the better the process works. It takes a conscious effort on the part of both the moderator and recorder to get the attention focused on the concept map. It is also quite possible that discussions can lapse back away from the map even after attention has been directed there for some time.

An alternative to the two-person moderator/recorder approach to knowledge elicitation is the use of a single elicitor who both interviews the expert and produces the concept map at the same time. One of the benefits of this approach is that since the elicitor's attention is directed toward the concept map, it is quite natural to have the expert's attention focused there as well. Although there are many benefits to having two elicitors, this approach affords a natural, easy way to get the session focused on creation of the concept map.

4.4 Creating Sub-maps including Placeholder Maps

Rapid-fire sessions can lead to the accumulation of a great many concepts in a surprisingly short period of time. When it appears that a large amount of detail is being generated in a map, it might become necessary to remove some of the detail, place it in what will be a lower level map, and link to it from the current map. Typically, one node is left in the more general map, and that particular concept is repeated with all the accompanying detail in the sub-map. An important issue with regard to the creation of sub-maps is the maintenance of some consistency in the level of detail that is removed, and the level of detail that remains. If topics are of similar granularity, it is poor structuring to have numerous details pertaining to one of the concepts remaining in the more general map while removing all the details of the other concept to a sub-map. The breakpoint between what is acceptable in this regard and what is not is a judgment, and accordingly, this is a guideline rather than a hard-and-fast rule.

As stated before, some experts methodically expand around a well-focused idea, but ones who do are rare. More often, experts, who tend to see most things somehow connected to most other things, meander around and it is the responsibility of a knowledge elicitor(s) to keep the focus on the topic at hand. If it is realized that an item seems to be related to the topic, potentially of interest, but outside the actual scope of the current map, it is useful to create a placeholder map, possibly with a focus question, for later sessions. The agenda for knowledge elicitation sessions is often quite fluid and takes form as the process unfolds.

There is an element of opportunism in the process whereby it is not usually possible to know in more than broad terms exactly what is best to elicit before-hand. The use of placeholder maps, some of which might be discarded later, is a good means to keep track of potentially interesting issues. An example from the turbine expert was that in discussing a loosely related issue, it was uncovered that he had unique methods of measuring very large things extremely precisely. He had to be able to measure 30 foot-long turbines down to microns and he had his techniques. Knowledge elicitation is usually with experts who have accumulated a lifetime of experience and it is difficult to know what is most important about what they know. Placeholder maps help to articulate possible areas that might be of interest. They can be prioritized by the KE team in terms of which might be the most profitable to explore because knowledge in that area is unique or poorly-documented.

5 “I missed that”

One of the most difficult aspects of managing an interactive knowledge elicitation session is not missing important ideas. This is not a universal problem since some true experts talk slowly, are very measured about staying on-topic, and methodically address a given topic as a concept map is constructed. Others, however, are very rapid-fire in their thoughts and words, putting out many ideas on potentially many subjects, and making it a struggle to keep up.

The single most effective way to avoid this problem and to settle into a productive session in which all the big ideas are captured, is to get the attention of the expert focused on the emerging concept map itself as a mediating representation among the participants. The expert gets visual cues on how quickly and accurately the ideas are being recorded, and this arrangement acts as a natural brake to keep the expert from going too quickly. Another aspect of handling this problem is that the elicitor should always feel free to ask the expert to slow down, repeat, rephrase, etc. It is typically the case that one does not wish to interrupt the thought processes of the expert, but to do so is clearly preferable than to miss important information. It has been shown (Hoffman, Coffey, & Ford, 2000) that interactive knowledge elicitation is an efficient process. For example, efficiencies are not gained by recording and transcribing sessions as an alternative to concept mapping. Accordingly, it is not a bad thing to slow down a bit.

A related issue to the problem of missing information is the fact that many experts tend to digress, ramble, or otherwise move off the subject. If it becomes evident that the expert is predisposed to do this, the knowledge elicitor should try to record the ideas, stop the expert, enlist his/her aid in making a judgment regarding whether the ideas are of sufficient importance to make a placeholder map, produce the placeholder as appropriate, and then get back on the topic. This is another example of the balance that must be struck between allowing the expert sufficient latitude to explore related ideas while keeping on subject and not missing important but not immediately relevant issues.

One last area of difficulty in adequately documenting knowledge on the fly pertains to illustrative stories or anecdotes. It is difficult to create concept maps interactively that contain all the richness and detail that is contained

in stories that illustrate a point an expert is trying to make. Instead of trying to keep up in such a circumstance, it might be better to plan to capture the story as video or in some other format. This approach is relevant to the idea of using the right tool for the job, the topic of the next section.

6 The Right Tool for the Job

Concept maps are good for the representation of conceptual knowledge and the interconnections among concepts in the domain. Tergan (2005) states that a benefit of having a structuring tool such as CmapTools (http://cmap.ihmc.us, CmapTools 2003; Cañas et al, 2004) is that content knowledge and information that augments and explains the concepts in a concept map greatly enhances the utility of the representation. It is clear that concept maps are not the ideal representation for all forms of knowledge. While various broad characterizations of knowledge are possible, Basque and Leonard (2004) used a form of concept mapping to distinguish among concepts, principles, procedures and facts. While each of these types of knowledge might appear as a node in a map, details pertaining to that type of knowledge might not. Concept maps are different than procedures or process flow charts, although one can construct a flow chart with typical concept mapping software. Facts are more suggestive of information than knowledge, and might be optimally represented in a list. The same might be said for Principles. Accordingly, it seems evident that different elements that might arise in interactive concept mapping sessions might be expressed in a variety of representations. This section will discuss some general guidelines for using the best representation.

6.1 When to stop mapping and start resourcing

The judgment of when to stop mapping and start using other accompanying resources is not simple to make. If known resources exist that elaborate an issue under consideration, they will, of course, be considered for use. Often, however, such resources are not identified until after some mapping has occurred. Additionally, as mentioned previously, some forms of knowledge are not easily rendered in a concept map. Illustrative examples may or may not be stored in concept maps. Stories captured on video are another example of items that might be better represented in other means than in concept maps.

Other examples of knowledge that is not best rendered in a concept map have been identified. For instance, derivations in a series of math equations with numbered equations and explanatory text is likely the best way to represent this type of knowledge. Comparing a number of items according to a number of characteristics readily lends itself to a matrix organization. Attempting to represent such information in a concept map will inevitably lead to a tangled map that is both difficult to compose and difficult to understand. A multi-dimensional comparison of two items is a special case of this idea and still better represented as a table. While representation of data in tables or equations might be the best form for an application, summarizations of the major conclusions that might be drawn from the data or the rationale for the equations might be captured in a concept map.

Another aspect that helps with the decision regarding when to stop mapping and start resourcing is the goal of the knowledge model. Briggs et al. (2004) point out that a knowledge model created at the NASA Center for Mars Exploration (CMEX) entitled "Return to Mars," was mainly meant to organize a large group of extant pictures and other resources pertaining to Mars. By comparison, the STORM knowledge model, also briefly mentioned in that paper, was built to capture deep expert knowledge pertaining to regional effects on weather forecasting. Although the CMEX knowledge model contained more concept maps than the STORM model, the narrower focus of the STORM model meant that its concept maps went into greater detail on individual topics.

The STORM model included many additional resources including videos of experts describing ideas that were deemed more comprehensible in video format. Additionally, Klein's Critical Decision Method (Klein et al. 200x), which is a detailed narrative on a timeline, proved useful for the representation of decision-making processes that unfold over time. Such representations are complementary to concept maps in the sense that they might capture highly detailed, focused knowledge that can be organized with concept maps.

The issue of how to identify accompanying resources must also be considered. It is to be expected that experts will refer to documentation as a routine matter during knowledge elicitation. In the course of mapping sessions, elicitors can note items to which the expert refers and record where they should go in a knowledge model. On the other hand, identification of resources can be treated as a separate, deliberate step. It is to be expected that some

knowledge domains will naturally have more resources available than others. For example, The CMEX work was meant to organize other resources from NASA's large collection.

6.2 Capturing Processes

One might initially capture process knowledge in a concept map. One of the most appealing aspects of capturing process knowledge is that conceptual knowledge pertaining to the rationale for the process might appear in the same map. A process map might start with an elicitation of the concepts pertaining to the process, some of which might be steps in the process and others not. As the map becomes well-populated, the steps in the process are identified and ordered. A feature of CmapTools called the "nested node" has proven useful for the representation of process information. The process name might appear with the nested node closed, and details of the process are viewed by opening it. On the other hand, tools that can help the user walk through processes represented as complicated decision trees might provide a more useful representation of a process than a concept map. In such circumstances, an initial round of concept mapping might be a good vehicle for the development of rules that ultimately reside in software to manage the decision tree.

7 Refining and verifying concept maps

Concept mapping is best viewed as an iterative process. After an initial round of mapping, it is always beneficial to revisit concept maps that have been created. Experts are typically able to identify multiple issues regarding representations that do not capture the precise meanings intended. Omissions are readily identified. Refinement of the wording of concept maps, particularly with regard to the linking phrases, is a critical part of the process. This is typically a more relaxed phase since the activity entails refinement of knowledge that is already there rather than frenetically attempting to capture it in the first place as it flies by.

Since some offline effort to refine concept maps between or at the end of a wave of sessions, to link them together, and to populate them with resources, occurs without the benefit of the expert, the possibility always exists that errors might be introduced into the concept maps or lower quality or inappropriate resources might be linked. It is helpful to refine maps on the evening on which they were elicited and are still fresh in the elicitor's mind. It is extremely important not to change the sense of what is in the map. The changes should be reviewed with the expert or experts the next day, particularly if more than trivial changes are made.

It should be noted that an additional aspect of this phase is that gaining a focus on the concept map itself is not a problem as it can be in the early phases of the work. The refinement phase is typically undertaken with the expert from whom the concept maps were elicited. It is a task of stepping through concept maps methodically and examining nodes, linking phrases, and links to other maps and resources. Even after protracted sessions, experts typically are able to identify changes to be made. This activity might be viewed as different from a verification phase that is performed with a different expert.

Some evidence exists (Hoffman, Ford, & Coffey, 2002) that the changes made by a different expert than the one from whom the concept map was originally elicited are relatively minor; perhaps on the order of 10% of the concepts and linking phrases might be changed. However, it is to be expected that if concept maps on the same knowledge domain are elicited from two experts, they might be quite different. Whether such differences are a consequence of different areas of interest within a domain, different use of vernacular, or differing constructions of truth is an open question.

8 Summary

This work seeks to enumerate very basic, practical guidelines and principles regarding interactive elicitation of concept maps and knowledge models for knowledge elicitation and preservation. After reviewing literature on knowledge elicitation with concept maps, the paper examines several issues. For instance, it is always important for elicitors who are not experts in the knowledge domain to prepare as best they can before sessions start. It is easy to lapse into the elicitation of very basic, generic knowledge from the expert's standpoint without sufficient advance preparation. One strategy that can mediate against eliciting superficial knowledge is the creation of a basic

knowledge model as part of the preparation phase. The overview of the knowledge domain facilitates making decisions regarding where to start with the expert.

As the sessions get underway, decisions regarding when to create sub-maps and placeholder maps are made. The idea of maintaining consistent granularity in a concept map when making sub-maps is addressed. The useful idea of creating placeholder maps when the discussion strays from the topic at hand is also described. The issue of when to stop mapping and start using other resources is addressed. This issue is difficult and involves judgments of the best representation to convey an item of interest. Several examples of alternative resource types are presented and described. The article closes with a discussion of how to verify knowledge models both as the emerging models are refined in nightly cycles that can be reviewed with the expert the next day, and with a different expert who is brought in to verify independently. Like all knowledge elicitation methods, knowledge modeling as defined at IHMC still has elements of art and craft in it, but an awareness of issues and strategies that have been uncovered over the years can produce more efficient and effective work.

Acknowledgements

The author wishes to thank Professor Joseph Novak for many years of guidance and collaboration in learning the art and craft of Concept Mapping. The author also wishes to thank Alberto Cañas and the CmapTools team for producing such a marvelous piece of software, and Robert Hoffman for many years of collaboration and for his contributions to the field of Knowledge Elicitation.

9 References

Basque, J., Imbeault, C., Pudelko, B., Lionard, M. (2004). Collaborative knowledge modeling between experts and novices: A strategy to support transfer of expertise in an organization. In: A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I, pp. 75-82). Pamplona, Spain: Universidad Pública de Navarra.

Brewer, I., & McNeese, M. (2004). Expanding concept mapping to address spatio-temporal dimensionality. In: A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I, pp. 101-107). Pamplona, Spain: Universidad Pública de Navarra.

Briggs, G., Shamma, D. A., Cañas, A. J., Carff, R., Scargle, J., & Novak, J. D. (2004). Concept Maps Applied to Mars Exploration Public Outreach. In A. J. Cañas, J. D. Novak & F. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I, pp. 109-116). Pamplona, Spain: Universidad Pública de Navarra.

CmapTools (2003). IHMC Concept map software, A knowledge construction toolkit. [Online] Retrieved 6/19/2006. http://cmap.ihmc.us/

Cañas, A. J., Coffey, J. W., Reichherzer, T., Hill, G., Suri, N., Carff, R., Mitrovich, T., & Eberle, D. (1998). El-Tech: A performance support system with embedded training for electronics technicians. Proceedings of the Eleventh Florida AI Research Symposium (FLAIRS '98), 79-83. Sanibel Island, FL.

Cañas, A. J., Hill, G., Carff, R., Suri, N., Lott, J., Eskridge, T., et al. (2004). CmapTools: A Knowledge Modeling and Sharing Environment. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I, pp. 125-133). Pamplona, Spain: Universidad Pública de Navarra.

Coffey, J. W., & Hoffman, R. R. (2002). A knowledge modeling approach to institutional memory preservation. The Journal of Knowledge Management, 7(3), 38-49.

Coffey, J. W. (1999). Institutional memory preservation at NASA Glenn Research Center. Technical Report, NASA Glenn Research Center, Cleveland, OH.

Coffey, J. W., Eskridge, T. C., & Sanchez, D. P., (2004). A Case Study in Knowledge Elicitation for Institutional Memory Preservation using Concept Maps. In: A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I, pp. 151-158). Pamplona, Spain: Universidad Pública de Navarra.

Coffey, J. W., Cañas, A. J., Novak, J. D., Hoffman, R. R., Carnot, M. J., & Jost, A. (2003). Facilitating the creation of graphical knowledge representations for brainstorming and decision support. Proceedings of the 7th World MultiConference on Systemics, Cybernetics and Informatics. (SCI2003), Orlando, FL. 198-202.

Dumestre, J. (2004). Using CmapTools software to assist in job task analysis. In: A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I, pp. 227-235). Pamplona, Spain: Universidad Pública de Navarra.

Ford, K. M., Cañas, A. J., Jones, J., Stahl, H., Novak, J., & Adams-Webber, J. (1991). ICONKAT: An integrated constructivist knowledge acquisition tool. Knowledge Acquisition, 3, 215-236.

Ford, K.M., Cañas, A.J., & Coffey, J.W. (1993). Participatory Explanation. Proceedings of the Sixth Florida AI Research Symposium (FLAIRS '93), Ft. Lauderdale, FL, April, 1993.

Ford, K. M., & Bradshaw, J.M. (1995), Beyond the Repertory Grid: New approaches to Constructivist knowledge acquisition tool development, International Journal of Intelligent Systems, 8, 287-333.

Hoffman, R. R., Coffey, J. W., & Ford, K. M. (2000). A case study in the research paradigm of Human-Centered Computing: Local expertise in weather forecasting. Technical Report, Institute for Human and Machine Cognition, Pensacola FL.

Hoffman, R. R., Shadbolt, N. R., Burton, A. M., & Klein, G. (1995), Eliciting knowledge from experts: A methodological analysis, Organizational Behavior and Human Decision Processes, 62, 129-158.

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical Decision Method for Eliciting Knowledge. IEEE Transactions on Systems, Man, and Cybernetics, 19: 462-472.

McNeese, M., Zaff, B., Brown, C., Citera, M. & Selvaraj, J. (1993). Understanding the context of multidisciplinary design: Establishing ecological validity in the study of design problem solving, Proceedings of the 37th Annual Meeting of the Human Factors Society, Santa Monica, CA.

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

Novak, J. D. (1998). Learning, creating, and using knowledge: Concept Maps as facilitative tools in schools and corporations. Mahweh, NJ: Lawrence Erlbaum Associates.

Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York: Cambridge University Press.

Tergan, Tergan S-O. (2005). Digital Concept Maps for Managing Knowledge and Information. In: Tergan S, Keller T (Eds). Knowledge and information visualization: Searching for Synergies. LNCS 3426. Heidelberg, Germany: Springer. 185-204.