A Summary of Literature Pertaining to the Use of Concept Mapping Techniques and Technologies for Education and Performance Support

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prepared for

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1. Executive Summary

Concept Maps are diagrams that represent organized knowledge (Novak & Gowin, 1984). This report is a summary and integration of published literature on the uses of Concept Maps to support human learning and workplace performance. It contains a summary of studies pertaining to the effectiveness of Concept Mapping for these purposes, and a description of commercial products that support Concept Mapping and related activities. The main goal of this report is to identify and highlight areas of application of Concept Mapping for learning (training, knowledge sharing, etc.) and performance support (decision-aiding, knowledge preservation, etc.).

1.1. Background and Theory Pertaining to Concept Maps

Concept Maps are graphical representations of knowledge that are comprised of concepts and the relationships between them. We define a *concept* as a perceived regularity in events or objects, or a record of events or objects, designated by a label. Concepts are usually enclosed in circles or boxes, and relationships between concepts are indicated by connecting lines that link them together. Words on the linking line specify the relationship between the concepts. The label for most concepts is a single word, although sometimes we use symbols such as + or %. Concept-link-concept triples form *propositions*, which are meaningful statements about some object or event. Sometimes these are called semantic units, or units of meaning. Figure 1 presents a Concept Map pertaining to Concept Maps.

Another characteristic of Concept Maps is that the concepts are represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged below. The hierarchical structure for a particular domain of knowledge also depends on the context in which that knowledge is being applied or considered. Therefore, it is best to construct Concept Maps with reference to some particular question we seek to answer, which we have called a *focus question*. The Concept Map may pertain to some situation or event that we are trying to understand through the organization of relevant knowledge, thus providing the context for the Concept Map.

Also important and characteristic of Concept Maps is the inclusion of "*cross-links*." These make explicit relationships between or among concepts in different regions or domains within the Concept Map. Cross-links show how a concept in one domain of knowledge represented on the map is related to a concept in another domain shown on the map. In the creation of new knowledge, cross-links often represent creative leaps on the part of the knowledge producer. An example in Figure 1 is the proposition "Perceived Regularities or Patterns begin with Infants" which is cross-linked to the proposition "Creativity begins with Infants."

A final aspect of the structure of Concept Maps is the inclusion of specific examples of events or objects. These can help to clarify the meaning of a given concept. Normally these are not included in ovals or boxes, since they are specific events or objects and do not represent concepts.

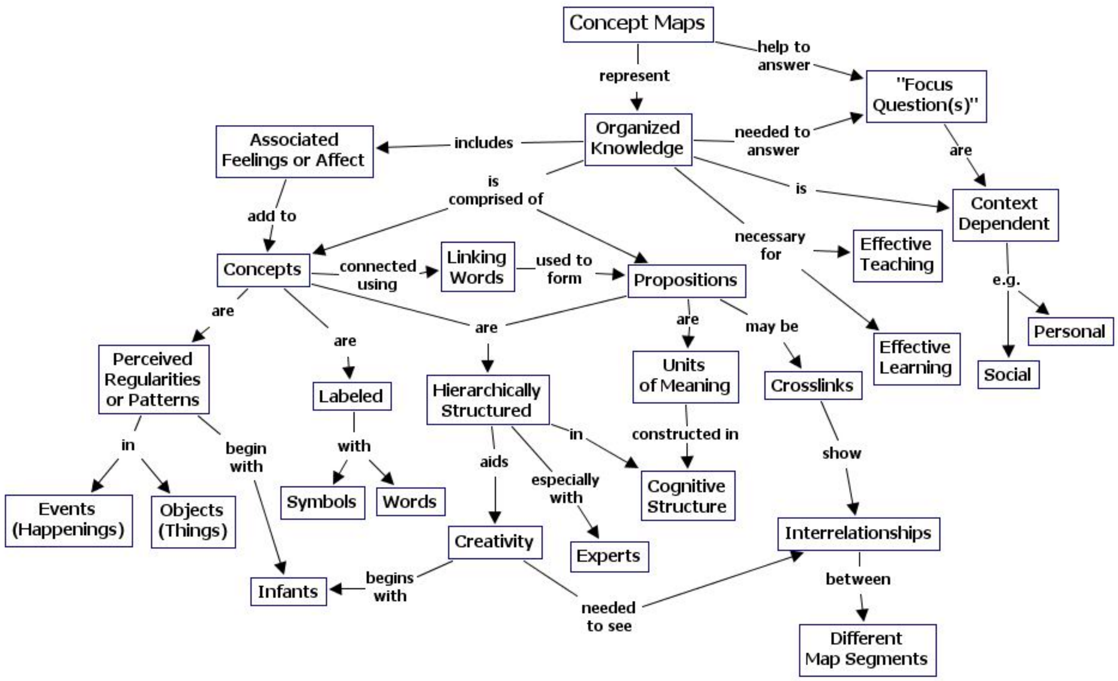

Figure 1. A Concept Map that describes Concept Maps.

Concept Maps were developed in the course of Novak's research program in which he sought to follow and understand changes in children's knowledge of science. Novak's work was based on the learning psychology of David Ausubel (1968, 1978). The fundamental idea in Ausubel's cognitive psychology is that learning takes place by the *assimilation* of new concepts and propositions into existing concept and propositional frameworks held by the learner. This knowledge structure as held by a learner is also referred to as the individual's *cognitive structure*.

One of the most fundamental goals in the use of Concept Maps is to foster meaningful learning. Ausubel made the very important distinction between *rote learning* and *meaningful learning*, and stated that meaningful learning requires three conditions:

1. The material to be learned must be conceptually clear and presented with language and examples relatable to the learner's prior knowledge. Concept Maps can be helpful to meet this condition, both by identifying general concepts prior to instruction in more specific concepts, and by assisting in the sequencing of learning tasks though progressively more explicit knowledge that can be anchored into developing conceptual frameworks.
2. The learner must possess relevant prior knowledge. This condition can be met after age 3 for virtually any domain of subject matter, but it is necessary to be careful and explicit in building concept frameworks if one hopes to present detailed specific knowledge in any field in subsequent lessons. We see, therefore, that conditions (1) and (2) are interrelated and both are important.

3. The learner must choose to learn meaningfully. The one condition over which the teacher or mentor has only indirect control is the motivation of students to choose to learn by attempting to incorporate new meanings into their prior knowledge, rather than simply memorizing concept definitions or propositional statements or computational procedures. The creation of Concept Maps supports the incorporation of new meanings into prior knowledge.

Another very powerful use of Concept Maps is as an evaluation tool, thus encouraging students to use meaningful-mode learning patterns (Novak & Gowin, 1984; Novak, 1998; Mintzes, Wandersee & Novak, 2000). Concept Maps are also effective in identifying both valid and invalid ideas held by students. This use will be discussed further in another section. They can be as effective as more time-consuming clinical interviews for identifying the relevant knowledge a learner possesses before or after instruction (Edwards & Fraser, 1983).

There is an important relationship between the psychology of learning, as we understand it today, and the growing consensus among philosophers and epistemologists that new knowledge creation is a constructive process involving both our knowledge and our emotions or the drive to create new meanings and new ways to represent these meanings. Learners struggling to create good Concept Maps are themselves engaged in a creative process, and this can be challenging to many, especially to learners who have spent most of their life learning by rote. Rote learning contributes very little at best to our knowledge structures, and therefore cannot underlie creative thinking or novel problem solving. Concept Mapping is an excellent exercise for the promotion of creative thinking and identification of new problem-solving methods.

1.2. Educational, Business, and Governmental Uses of Concept Mapping

Concept Mapping has been put to many uses in education, business and government. One of the original uses in education was for the assessment of what a learner knows. Concept Maps can be used to externalize and make explicit the conceptual knowledge (both correct and erroneous) that students hold in a knowledge domain. The process of Concept Mapping for educational purposes can foster the learning of well-integrated structural knowledge as opposed to the memorization of fragmentary, unintegrated facts.

In educational settings, Concept Maps can also be used to organize instructional materials for individual courses or entire curricula. Concept Maps have been used to serve as navigational aids for hypermedia, as a scaffold for understanding, for consolidation of educational experiences, to improve affective conditions for learning, as an aid or alternative to traditional writing, and to teach critical thinking.

Concept Maps and Concept Mapping also have utility in corporate and governmental organizations. To the degree that these entities carry out education and training of their personnel, educational applications are pertinent here as well. Furthermore, Concept Mapping can be used for knowledge capture – for the elicitation of expert knowledge that an organization might wish to preserve and share with others. In addition, Concept Mapping can be used in support of group processes such as brainstorming. A Concept Map's concise, visual representation of knowledge "at a glance" can simplify the conveyance of understandings, and fosters discussion. Concept Maps can serve as a tool for reaching consensus through the creation and refinement of a Concept Map upon which members of a group can agree.

1.3. Limits on Our Ability to Report

A great deal of literature pertains to the use of Concept Mapping for educational purposes in educational settings. It is natural that this area would contain a large body of literature since it is in educational settings that Concept Mapping originated. The shear volume of this literature makes it infeasible to perform a truly comprehensive review in which each and every report is summarized in detail.

The opposite problem seems to exist in the uses of Concept Mapping tools and similar knowledge representations to enhance workplace performance. The use of such tools in competitive corporate settings is often viewed as an element of competitive advantage that companies are somewhat reluctant to share. For this reason, public literature pertaining to specific uses of Concept Mapping and similar strategies in business settings tends to be much less voluminous and somewhat more superficial and anecdotal than literature from educational settings.

1.4. Major Conclusions of this Report

Concept Maps differ from other types of mapping systems, such as Knowledge Maps, Conceptual Graphs, and Mind Maps because of: their grounding in Ausubel's Assimilation theory of learning, their semantic and syntactical (structural) organization, the nature of concepts that comprise the nodes in a Concept Map, and the unconstrained nature of linking phrases. A standard procedure for Concept Map construction involves defining the topic or focus question, identifying and listing the most important or "general" concepts that are associated with that topic, ordering the concepts from top to bottom in the mapping field, and adding and labeling linking phrases. Once the preliminary Concept Map has been built, cross-links are identified and added, and a review of the map for completeness and correctness is performed.

Several alternative approaches to Concept Map construction exist. Some of these mapping variations are based on the use of software tools, the pre-specification of concepts and/or link labels, and individual versus collaborative mapping. Individually produced Concept Maps and those produced by groups can be made with the assistance of human or software-based facilitation. Many facilitation procedures are possible in Concept Map construction, ranging from support provided to novices who are learning to create Concept Maps, to support of a group of experts who work in conjunction with a facilitator or knowledge engineer.

Efficacy studies reveal that when Concept Mapping is used in a course of instruction, it is better that it be an integral, on-going feature of the learning process, not just some isolated "add-on" at the beginning or end. In this regard, Concept Mapping appears to be particularly beneficial when it is used in an on-going way to consolidate or crystallize educational experiences in the classroom, for example, a lecture, demonstration, or laboratory experience. In this mode, learners experience an educational event and then use Concept Mapping in a reflective way to enhance the learning from the event. There is also indication that learning effects are enhanced when in the course of Concept Mapping learners adopt an active, deep and questioning approach to the subject matter. Such active, self-engaging, transformational interaction with learning material has been suggested to enhance learning in general (e.g., Feltovich, Spiro, & Coulson, 1993) and this appears to carry over to learning with Concept Maps as a tool.

When Concept Mapping is compared with other sorts of activities, such as outlining or defining concepts, that also can induce the learner to take a thoughtful, systematic approach to engaging subject matter, the positive benefit of Concept Mapping often diminishes (a finding noted also in the review by Horton, 1993). However, even in these situations, it appears that Concept Mapping is especially good, in comparison to other interventions, for the learning of *relationships* among concepts.

From several of the studies reviewed, there is indication that Concept Mapping may be particularly beneficial for lower ability learners, partly because it does induce the active, inquiring, orderly approach to learning that is likely a more natural part of the higher ability student's approach to learning. On the other hand, when learners *are not yet facile* with constructing Concept Maps, there is some indication that the cognitive load of creating maps from scratch may hinder learning. When students are novice mappers, other "scaffolded" ways of interacting with Concept Maps, for example, filling in the blank content nodes of a Concept Map already containing the labeled relationships of a completed Concept Map, may be beneficial.

Numerous educational applications of Concept Mapping can be identified. Including as: 1) a scaffold for understanding, 2) a tool for the consolidation of educational experiences, 3) a tool for improvement of affective conditions for learning, 4) an aid or alternative to traditional writing assignments, 5) a tool to teach critical thinking, 6) a mediating representation for supporting interaction among learners, and 7) an aid to the process of learning by teaching. Several studies were examined in which Concept Mapping was used to identify students' current understandings, misconceptions and conceptual change. Concept Maps have been used in collaboration and cooperative learning, and as a formal assessment tool. Concept Maps have been used to organize and present information, including use as an Advance Organizer, use by instructors for course or curriculum design, and use as a navigational aid in hypermedia.

A major lesson learned regarding the use of Concept Maps in educational settings is that the nature of the learner's mental interaction with the subject matter to be learned during the building of the concept map is key to the learner's achievement. The interaction cannot be passive if learning is to occur. Concept Mapping is greatly enhanced when a teacher (or other "facilitator" working with a learner), the learner him of herself, a device (e.g., computer generated prompts), or the nature of the interaction in a learning group promotes active inquiry and organization by asking questions, prompting for explanation and justification, requesting clarification, requesting embellishment, encouraging connection among elements, encouraging the learner to formulate questions about the material, and so forth.

Another lesson is that with regard to scoring methods for Concept Maps, a number of methods have been developed which do not seem to be as indicative of the structure of knowledge as traditional Concept Map scoring methods, but rather are focused on the proposition or concept level. These methods may show greater agreement with traditional measures of achievement but basing assessment of achievement on the inclusion of simple propositions or concepts is unlikely to motivate learners to learn new information in a meaningful and structured way.

With regard to the use of Concept Maps for navigation, another lesson is that the structure of Concept Maps that are carefully constructed may assist learners in finding information more quickly. However, maps constructed to be effective in communicating the structure of information cannot be too complex. Training in concept mapping may be useful in helping learners use the linking phrases and concepts in the map more effectively for learning. However, to some extent the value of the map will depend on the user's goals – whether those goals are to find the answer to a specific question or problem, or to learn more about the structure of a particular domain of knowledge. Map characteristics such as organization, color coding, and animation may be important in determining the utility of concept maps used for navigation; however these characteristics are largely unexplored, except in anecdotal evidence (and a few exceptions from TCU group).

Finally, both concept maps and collaborative learning have been shown to have educational benefits. Another lesson is that the two can be combined to produce synergistic beneficial effects. This can be useful in promoting collaborative activities among learners and in enhancing the process of knowledge construction. More active involvement in learning can be provided by the concurrent use of these techniques. Current technology and software have provided the capability of networked and remote collaboration. This makes the benefits of collaborative concept mapping more accessible for both educational and business uses. Appendix 2 provides a partial summary of these domains.

Concept Mapping has had widespread use as a knowledge elicitation (KE) tool. In terms of its yield of propositions that are informative about a domain, Concept Mapping is at least as efficient as other available KE methods. Concept Mapping is likely the most efficient method for generating models of domain knowledge. As a KE procedure, it has been successfully employed to form mediating representations and interfaces for intelligent software (i.e., knowledge-based systems and tutoring systems).

Software systems that have been developed using concept Mapping, and software systems that utilize Concept Maps (i.e., as interfaces) have generally been based on a satisficing criterion. Evidence of usefulness, usability, performance enhancement, or organizational effectiveness is not provided. However, this application of Concept Maps has a clear track record of successful demonstrations in a range of domains. Further research is needed to demonstrate usefulness, usability, and net performance gain using Concept Map-based knowledge acquisition or Concept Map-based intelligent systems.

The recognition that the aggregate knowledge of an organization is a valuable asset that must be protected, maintained and augmented, has created a rapidly escalating interest in knowledge elicitation and representation, facilitation of brainstorming techniques through concise, graphical representations of knowledge, etc. The literature suggests that a variety of representation schemes are needed to capture the full gamut from conceptual knowledge to procedural knowledge. Clearly, it is important to choose "the right representation for the job," but for many jobs, Concept Maps quite clearly have a role to play in the form of a simple, intuitive knowledge representation scheme.

Many of the studies pertaining to Concept Mapping uses in business and industry are preliminary. We believe this is so because many organizations are just now attempting to ramp up large-scale capabilities to preserve, generate and share knowledge. The quality of the work that is reported is variable. It is clear that it is difficult to require already over-worked employees to perform additional tasks pertaining to knowledge capture. On the other hand, clear successes such as those described by McNeese et al. (1990), suggest that uses of graphical tools such as concept maps have a part to play in knowledge generation, capture and representation.

The military studies illustrate a range of uses for Concept Maps in military settings. There is substantial overlap with the uses that have been identified in the civilian sector: teaching and learning, brainstorming, expertise capture for knowledge-based systems, etc. It is quite clear that group elicitation and brainstorming approaches could be quite useful for mission planning and other strategic and tactical planning.

Numerous graphical software packages and tool suites can be used as learning devices, for knowledge elicitation and representation, for brainstorming, etc. A number of these tools are general-purpose diagramming packages that allow the user to create many kinds of graphical representations. Other software tools are more special-purpose with specific capabilities such as the ability to advise the user or enforce creation of a specific type of diagram, to link to a database, to generate html representations of the maps they are used to create, etc.

With regard to software tools used to create Concept Maps and similar representations, two basic distinctions may be identified. The first distinction is between general drawing tools that can be used to create a variety of diagram types but do not provide guidance in the effective construction of any given type, and more special-purpose tools that cannot be used to create as many different types of diagrams. While the general tools offer flexibility, they typically do not provide guidance in the effective construction of any given type of diagram. The special purpose tools give more targeted help on the types of diagrams they can be used to create. They all have their own unique characteristics with regard to how general or special-purpose they are, the sorts of diagrams they support, and the level of help they provide to the user.

The second distinction involves the quality of the representations themselves. A well-conceived software package that is used to create representations that are not particularly rich, or that do not fit the intended purpose of the user, may not be very useful. On the other hand, a powerful tool that is difficult to use or only supports a limited range of not particularly rich representations is not ideal either.

2. Construction Methods and Styles for Concept Maps

Numerous mapping systems have been developed that enable the graphical depiction of ideas and concepts, e.g., Concept Maps, Knowledge Maps, Mind Maps, Cognitive Maps, and Semantic Networks. Concept Maps differ from these other superficially similar types of representations in a variety of ways. Essentially, Concept Maps are defined by:

1. Their theoretical basis in Ausubel's Assimilation Learning theory and constructivist epistemology
2. Their semi-hierarchical organization,
3. The use of unconstrained and meaningful linking phrases, and
4. The way concepts are defined.

The other similar representations are discussed in *Appendix A*.

2.1 Distinguishing Characteristics of Concept Maps

This chapter presents an elaboration of these distinguishing characteristics of Concept Maps, followed by some examples of Concept Maps. A standard method of Concept Map construction is presented along with variations, such as map facilitation procedures or interviews, and mapping by groups in collaborative settings, rather than by individuals.

Underlying Theory. Concept Mapping is grounded in a sound cognitive learning theory, Ausubel's Assimilation Theory (Ausubel, 1968; Ausubel, Novak, & Hanesian, 1978). Assimilation theory posits that new knowledge can be learned most effectively by relating it to previously existing knowledge. Concept Maps may be viewed as a methodological tool of Assimilation theory that displays fundamental elements of the theory such as subsumption, integrative reconciliation and progressive differentiation.

Semi-Hierarchical Organization. The basic motivation for the hierarchical arrangement of concepts in Concept Maps comes from Ausubel's notion of subsumption, that more general, superordinate concepts subsume more specific, detailed concepts. This theoretical notion translates to an arrangement of concepts from those that are more general toward the top of the page, with those that are more specific or detailed distributed beneath. In practice, the concepts in Concept Maps are not arranged in a strict hierarchy, but are arranged in a semi-hierarchical manner. Concept Maps allow for the representation of non-hierarchical relationships or cross-links, as well as other types of non-hierarchical arrangements.

Labeled Links. Another defining factor of Concept Maps is the use of linking phrases between concepts. Novak & Gowin (1984) state that a linking phrase should join concepts to form a meaningful proposition, which is a basic unit of knowledge according to the theory of meaningful learning and Ausubel's Assimilation Theory. Concept mapping theory does not constrain the labels that can be used, allowing map makers more freedom and precision in describing the relationships among concepts. Researchers using other types of graphing methods have prescribed a limited number of linking phrases that, they claim, can be used universally. Alternative policies regarding the use of linking phrases are described in the Appendix on other mapping systems.

Definition of Nodes. All of the graphing systems we have mentioned make some distinction between nodes and links. In Novak & Gowin's (1984) seminal work on Concept Mapping, a concept is defined as a "perceived regularity in objects or events". Though one must accommodate the fact that concepts can denote things that cannot be perceived (e.g., unicorns), this remains a good working definition. Typically a concept is expressed using one or just a few words, one of which is a noun or gerund. Other graphing systems maintain this definition of concept (e.g., Fisher, 1990; Jonassen, 2000; Herl, O'Neil, Chung & Schachter, 1999; O'Neil, 1999). However, the Mind Mapping methodology (Buzan & Buzan, 1996) allows for concepts (or nodes) that can be images, thoughts, ideas, or sentences. In Cognitive Mapping (Ackerman & Eden, 2001; Eden & Ackerman, 2001), the nodes are regarded as "ideas," which can be sentences or paragraphs. In the Texas Christian University (TCU) version of Knowledge Mapping, (Bahr & Dansereau, 2001; Chmeilewski & Dansereau, 1998; Lambiotte, Skaggs & Dansereau, 1993; O'Donnell et. al., 2002; Rewey, Dansereau & Peel, 1991) which uses a restricted set of linking phrases, nodes are sometimes concepts in the sense that we understand them, and sometimes ideas or even entire paragraphs. Limiting node contents to concepts allows for a more explicit representation of the interrelationships among concepts, and is a defining characteristic of our notion of Concept Maps.

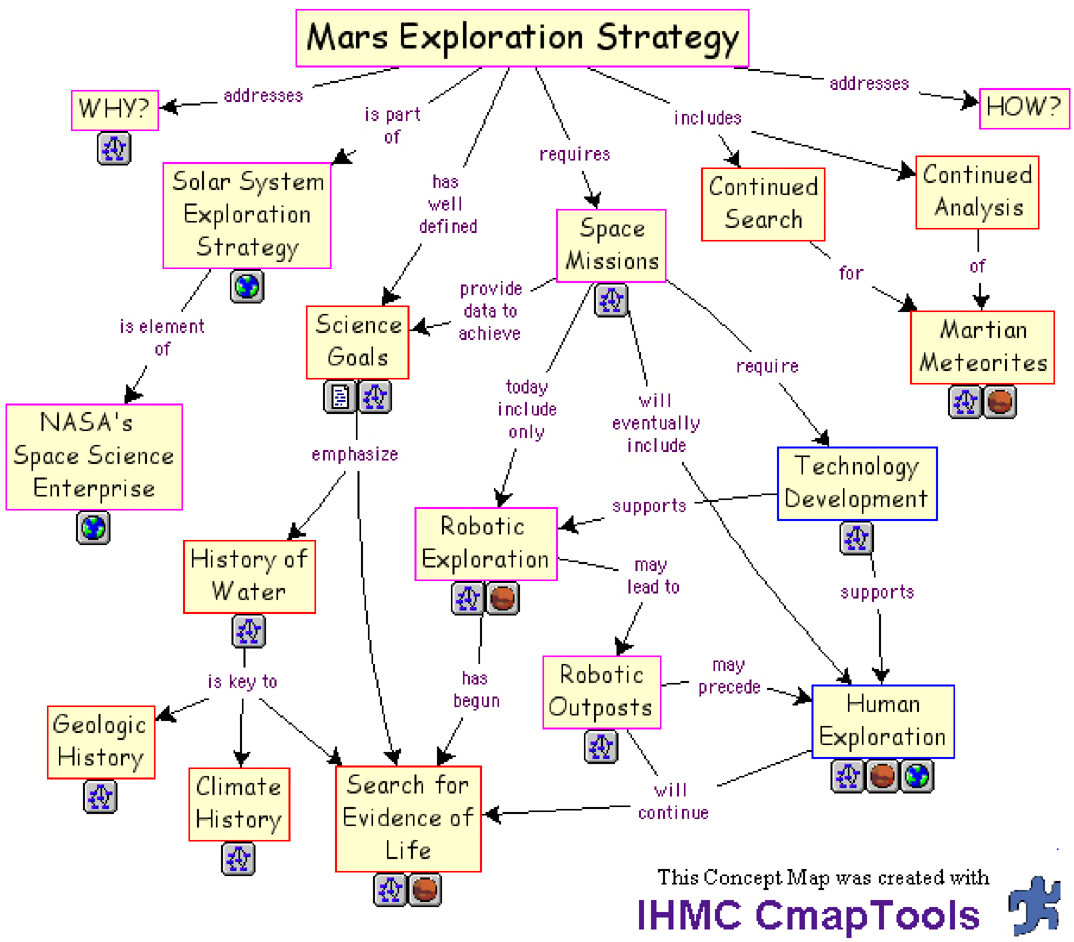

Figure 2. A Concept Map pertaining to Mars Exploration Strategies.

2.2 An Example Concept Map

This section contains an example of a Concept Map that illustrates their defining characteristics. Figure 2 presents a Concept Map that was created in work performed at NASA Ames research Center. The Concept Map was created by an expert in Mars exploration who had received minimal training in Concept Map construction, but who quickly became highly proficient at map creation.

The concepts in this Concept Map are surrounded by boxes, and the Linking Phrases reside on the directed arcs between the concepts. The linking lines are all labeled with Linking Phrases that make explicit the relationships among the concepts. The concepts are single words or short phrases rather than sentences or paragraphs. The Concept Map contains many concepts that are richly interconnected. Concept, link, concept triples read propositionally as in the proposition "Science Goals emphasize Search for Evidence of Life." The Map includes several cross-links that illustrate the conceptual interconnectedness of the concepts. The proposition "Space Missions provide data to achieve Science Goals," is an example of cross-linked concepts.

The Concept Map has a basic ordering of the concepts from general to specific from the top to the bottom, illustrating Ausubel's notion of subsumption. At the top of the Concept Map, the most general, superordinate concept, "Mars Exploration Strategy" appears. Just below that are several concepts such as "How," "Why," "Continued Search," and "Continued Analysis." Further down in the map are more detailed concepts such as "Robot Exploration" and "Human Exploration."

2.3 Construction Methods for Concept Maps

Concept Maps can be constructed by using a variety of methods. The method that is employed depends on the purpose of map construction. Concept Maps can be constructed either by hand or with the assistance of software that supports specific tasks or general diagramming. Concept Maps can be constructed by individuals or groups, either with or without facilitation.

A Standard Concept Map Construction Method. The Concept Mapping method defined by Novak & Gowin (1984) involves a series of steps.

1. Define the topic or focus question. Concept Maps that attempt to cover more than one question may become difficult to manage and read.
2. Once the key topic has been defined, the next step is to identify and list the most important or "general" concepts that are associated with that topic.
3. Next, those concepts are ordered top to bottom in the mapping field, going from most general and inclusive to the most specific, an action that fosters the explicit representation of subsumption relationships (i.e., a hierarchical arrangement or morphology).
4. Once the key concepts have been identified and ordered, links are added to form a preliminary Concept Map.
5. Linking phrases are added to describe the relationships among concepts.
6. Once the preliminary Concept Map has been built, a next step is to look for cross-links, which link together concepts that are in different areas or sub-domains on the map. Cross-links help to elaborate how concepts are interrelated.
7. Finally, the map is reviewed and any necessary changes to structure or content are made.

Figure 3 presents a Concept Map that illustrates several points regarding Concept Map construction. It is a Concept Map that is in-progress by Navy students. They started by identifying and entering many of the important concepts that they wanted to consider. Some of the concepts have been linked together by linking phrases. The concepts in the lower right portion that are not yet linked into other concepts are part what we call the "parking lot" where concepts for which relationships haven't been established are located. The students creating this Concept Map are on step 4 from the previous list. They have defined a question, "What is Solar Radiation?" They have identified and entered the basic concepts, distributed them from general to specific, and started linking them together.

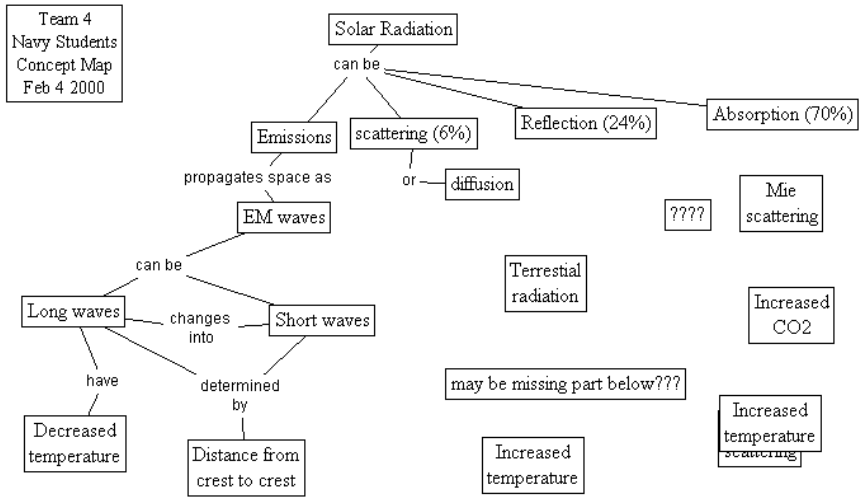

Figure 3. A Concept Map in progress on Solar Radiation from Navy student Aerographers.

Figure 4 contains the final version of the Concept Map from Figure 3. Students have completed the process of identifying concepts, adding several more to the previous map. They have linked the concepts together, and identified cross-links. This map displays a good vocabulary of concepts for novice Aerographers, and a well-integrated set of linking phrases.

The long, sweeping links among "Greenhouse effect", "Short waves," and "Absorption," illustrate the cross-links. Although the labeling of the cross-links could be improved, the fact that they are there at all indicates that the students had some sense that a relationship exists among these rather disparate concepts. Concept Mapping facilitates the learning process by allowing the instructor to identify missing or irrelevant concepts, trivial or incorrect linking phrases, etc. The Concept Map provides the basis for discussions between students and their instructors, to clarify relationships such as the one depicted, and generally to gain a better understanding of the subject matter.

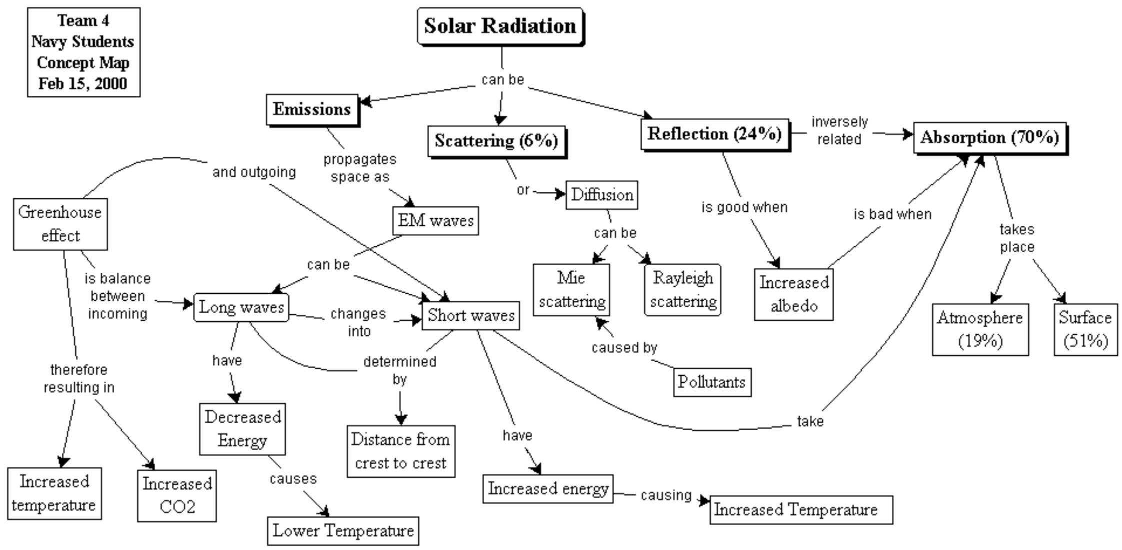

Figure 4. The final Concept Map on Solar Radiation from the Navy student Aerographers.

It should be noted that the process described here contains descriptions of the activities that typically occur in a successful Concept Mapping effort. It is rare that the actual process unfolds in such a clearly proscribed, sequential fashion. Often, Concept Map creators simply jump right in, creating concepts and linking them together. As in the conduct of most processes, more initial thought and overall systematicity fosters better results. The next sections describe other methods of Concept Map construction.

2.4 Variations on the Standard Map Construction Method.

A characteristic of the standard method of Concept Map construction described above is that the only constraints are the structural format of the map (subsumption expressed in a semi-hierarchy), and the limits imposed by using appropriate concepts and linking words. This method is preferred because it allows the creator freedom in the representation of knowledge. Other methods of map construction have been used to serve a variety of goals, including ease of computer implementation, ease of construction by students and so forth. Researchers from CRESST have described and compared a number of Concept Mapping techniques (Ruiz-Primo et al., 2001).

Ruiz-Primo et al. (2001) suggested that the degree of control or directedness in map construction differs in different mapping tasks. Map builders can be given the structure of the Knowledge Map, and lists of concepts and linking words to use to fill in the slots in the graph (a fill-in task). At the opposite extreme, the creator may be required to provide all concepts and linking phrases (a graph-from-scratch task). Aside from encouraging the semi-hierarchical format, the method proposed in Novak & Gowin (1984) method is a low-directedness mapping task. Ruiz-Primo et al. (2001) have suggested that graph construction tasks that are low in directedness may provide clearer insights into differences among students' knowledge structures.

Other Concept Mapping methods include variations designed to address specific tasks or settings. For example, Concept Maps can be constructed on the basis of interviews with students, experts, or other individuals. Concept Maps can be constructed by individuals or by collaborative groups, either in the same location or in remote locations, facilitated by computer networks. Concept Maps can be constructed with or without the use of a facilitator, either within a group or an individual setting. In either case, the facilitator may simply play the role of transcriptionist, or may actively promote elaboration or clarification of ideas in the Concept Map, and improvement of map structure. Concept mapping software has been designed to provide different types of facilitation for map construction, including online scoring and assessment of maps, or suggestions about improvements that may be made to the Concept Map.

2.5 Collaboration in the Construction of Concept Maps.

Although the standard method of Concept Mapping presumes that a Concept Map can be made to represent an *individual's* current level of knowledge and understanding, in many cases Concept Maps can be constructed as part of a collaborative group process. Concept Mapping can facilitate the exchange of information in a group, can make the viewpoints of individual collaborators more clear, and can encourage participation in the collaborative process. In educational settings, collaborative Concept Maps have been used for group projects, and have been compared to other types of group projects such as posters (e.g., Van Boxtel, Van der Linden & Kanselaar, 1997, 2000). In business settings, Concept Maps have been used to facilitate discussions among different groups within a company. Creation of collaborative Concept Maps by experts has been used to preserve organizational knowledge (Huff & Jenkins, 2002; Johnson & Johnson, 2002) Other types of graphing methods have been used in business for the purpose of problem solving and project management.

Collaborative creation of Concept Map may take many forms. Sessions may be conducted face-to-face or at a distance, and may be synchronous (all participants working concurrently) or asynchronous (e.g.: one collaborator completes edits and then another collaborator edits). Collaborations in the construction of Concept Maps in any of the contexts described in the previous paragraph can be performed locally or at a distance and synchronously or asynchronously.

As in the case of individual map construction, a well-defined focus question must be formulated. One method of collaborative Concept Map construction entails group identification of concepts and their relationships. One means of improving efficiency in group Concept Map creation is by the identification of a group moderator and a recorder or "driver" who actually records the concepts and builds the Concept Map. Negotiation and compromise must take place in the group construction of a Concept Map. It should be noted that participants might have irreconcilably different opinions that are made evident by the process. Such differences can cause the mapping process to stall. In such cases, it is probably best to separate out the conflicting ideas into two Concept Maps, and continue in separate groups. An attempt to reconcile differences can be made when both positions are clearly mapped.

Another form of collaboration in Concept Map construction is allowing the user access to related maps in development by others. There are multiple ways to provide this capability, including searching for related maps on public servers and collaboration capabilities provided by a software system. Cañas, Hill, Granados, Pérez & Pérez (2003) describe the extensive networking provided by the CmapTools software in support of synchronous and asynchronous collaboration and sharing during Concept Map construction. A different form of collaboration is proposed by Cañas et al. (2001), whereby a Knowledge Soup stored in a shared server allows students from distant schools to share claims (propositions) derived from their concept maps regarding any domain of knowledge being studied.

The literature also contains descriptions of the use of collaborative Concept Mapping in business settings (Novak, 1998; Fraser & Novak, 1998). Other group graphing methods and problem-solving techniques have been used in business settings. For instance, the collaborative use of Decision Explorer "Cognitive Maps" (Ackerman & Eden, 2001; Eden & Ackerman, 2001), "QuestMaps," (Conklin, 2002a; Conklin, 2002b; Conklin et al., 2002) and "Mind Maps" (Buzan & Buzan, 1996), suggests a growing interest in collaborative mapping techniques in business. However, our ability to describe the use of Concept Maps in business has been limited by the availability of literature pertaining to such uses, since confidentiality issues are significant in business settings.

2.6 The Facilitation of Concept Map Construction: Human Facilitators and Computer Support

Facilitation in the creation of Concept Maps can take several forms. A distinction can be made between assistance that is provided by human facilitators and assistance that is provided by the computer software that is used to construct Concept Maps. The nature of the facilitation depends on the goals of the mapping effort. If the goal is to use Concept Mapping in an educational setting to help students learn meaningfully, or for the assessment of structural knowledge, then the facilitator is essentially a teacher who must help the student learn how to make Concept Maps. Guiding students through the steps in the standard method described earlier and presenting examples of good Concept Maps are effective strategies to pursue this end.

If Concept Mapping is being used as a vehicle for knowledge elicitation, the facilitator plays a different role. In this case, the expertise resides within the expert, and the facilitator's role is to help create, or co-create with the expert, an explicit representation of that knowledge in a Concept Map. A facilitator in this setting may perform several functions including that of a knowledge elicitor, an interviewer who simultaneously creates a Concept Map reflecting the ideas that emerge from the interview, a "cheer leader" who encourages an effort to achieve clarity, consistency, and completeness, and even a monitor to encourage all the various group members to become involved in the mapping process.

When group Concept Mapping is being performed, it is desirable to allow the emerging Concept Map to be viewed by all participants by using computer software and a projector, or by creating a representation on a whiteboard or with Post-It™ notes. Any of the group members can facilitate insofar as they contribute to the attempt to refine the Concept Map. The role of a designated facilitator is to assist in the elicitation of knowledge and ideas from group members, and to assist in construction of a Concept Map representation that adequately represents the necessary information in a well-designed and readable Concept Map.

Another type of support might come from the software itself. Ideally, electronic facilitation might provide an individual with information about good Concept Mapping form and process (e.g., hierarchical structure in maps, the definition of focus questions, adequate distinction between concepts (nodes) and linking phrases, clear specification of linking phrases and so forth). Although this level of support may seem to be relatively basic, providing such feedback is a very difficult task to automate.

Tools may also provide differing amounts of support for users in terms of pre-defined concepts and links. As discussed earlier, the standard Concept Mapping procedure does not specify a set of linking phrases (though examples may be offered), to allow for the most comprehensive expression of knowledge. However, in many educational settings (such as those defined by Chung et. al., 2002) graphing and assessment procedures have led to the development of constrained map authoring systems, in which the concepts and linking phrases can be pre-defined based on expert analysis of the domain before student mapping. The graph construction process allows users to choose the concepts and linking phrases. This is a limited form of facilitation.

In addition, Concept Map systems might provide online access to WordNet, the Web or other related information directories, which may provide access to concepts and relationships that could or should be incorporated within a given Concept Map on a given topic. Cristea & Okamoto (2001) describe a course authoring system in which manual linking of course topics in a Concept Map can be aided by automatic linking of topics based on keywords defined in the course material. The instructor or course designer is then asked to verify these connections. Cañas et al. (2002) discuss a new capability in CmapTools that analyzes the map being constructed and uses its topology and semantics to mine the WWW and suggest concepts that the Concept Map creator might want to incorporate into the Concept Map. Leake et al. (2002) present a similar support mechanism that suggests linking phrases and related concept maps during the process of concept map construction using CmapTools, and suggests topics for new concept maps related to the one under construction (Leake et al. 2003). CmapTools also provides access to definitions, synonyms, and other terms related to a word in a concept or linking phrase (Cañas, Valerio, LaLinde-Pulido, Carvalho & Arguedas 2003). Clearly, Concept Map creation can be facilitated in a variety of ways that involve human intervention and machine assistance.

3. Applications in Educational Settings

The purpose of this chapter is to describe the many and varied ways that Concept Maps have been used in education. Before addressing educational uses of Concept Mapping, we note a few publications that have had a similar purpose.

In an ERIC digest publication, Plotnick (1997) reviewed uses of Concept Maps in education. This document provided a brief history of Concept Mapping, suggested potential uses of Concept Mapping in education, advantages of Concept Mapping (mostly based on visual representation), and advantages of computer support for Concept Mapping. These included the dynamic nature of linking, conversion of Concept Maps to other formats, and electronic storage. Uses for Concept Mapping Plotnick addressed include creativity, hypertext design (or design of other complex structures), learning, assessment, brainstorming, communication of complex ideas, and so forth.

White & Gunstone (1992) described uses of Concept Maps in education that are primarily based on assessment of changes in learner's understanding. These uses might include assessment of understanding of a limited aspect of a topic, assessment of whether learners can make links among concepts and the changes that occur in these links, assessment of whether learners understand goals of instruction, identification of which concepts are perceived as key concepts by learners, and promotion of collaboration among learners.

Other overviews of educational applications of Concept Mapping include Pankratius & Keith (1987) and Novak & Gowin (1984). In addition, Good, Novak & Wandersee (1990) acted as co-editors for a special issue of the Journal of Research in Science Teaching (1990, Volume 27). A special double issue of the Journal of Interactive Learning Research (1997, Volume 8, Number 3/4) also focused on Concept Mapping.

3.1. Uses of Concept Maps as a Tool for Support of Learning

In this section, we concentrate on maps constructed by students to foster learning. As an overview, Concept Maps created by students can be used in several ways to facilitate meaningful learning. Novak & Gowin (1984, Chapter 2) pointed out that Concept Maps are a kind of schematic summary of what students know. They can be used to display students' prior knowledge about a given topic, or they can be used to summarize what has been learned, for example, after reading an assignment or completing some other classroom lesson. In this regard, Concept Mapping is often used for note taking or as a study aid. Novak and Gowin noted that the act of mapping is a creative activity, in which the learner must exert effort to clarify meanings, by identifying important concepts, relationships, and structure within a specified domain of knowledge. The activity fosters reflection on one's knowledge and understanding, providing a kind of feedback that helps students monitor their learning and, perhaps with assistance of teachers or peers, focus attention on learning needs. As a creative activity, Concept Mapping can also be used as a planning tool or as an alternative to essay writing.

From the volume of literature on the subject of uses of Concept Maps, it is easy to conclude that the most prevalent use of Concept Mapping is for teaching and learning. Many studies have shown that mapping yields benefits for learning (although some have not – see Horton et al., 1993, for a review of such studies). In the following sections, we will illustrate some of the ways of using Concept Maps that have been shown to enhance learning and discuss briefly the kinds of students that mapping seems to help most. A variety of uses of concept maps have been identified including:

- as a scaffold for understanding,
- for consolidation of educational experiences,
- to improve affective conditions for learning,
- as an aid or alternative to traditional writing,
- to teach critical thinking, and
- as a mediating representation.

3.1.1 Identifying current understanding, misconceptions, conceptual change

What conceptual understandings students achieve in a new learning activity is highly dependent on what they already know. Concept Maps have been used to examine students' prior knowledge, to track a student's progression of knowledge throughout a course, to compare students at different levels of knowledge and so forth (Adamczyck & Willson, 1996; Cho, 1988; Hoz, Bowman & Kozminsky, 2001; Pearsall, Skipper & Mintzes, 1997; Songer & Mintzes, 1994; Troncoso, Lavalle, Curia, Daniele & Chrobak, 1998). Concept Maps have also been used to identify specific misconceptions in knowledge (e.g., Gonzalez, 1997; Regis & Albertazzi, 1996; Trowbridge & Wandersee, 1994), and to identify alternative educational approaches to address misconceptions (Kinchin, 1998; McNaught & Kennedy, 1997; Passmore, 1998). Teachers and students are often able to more clearly identify misconceptions within the context of a Concept Map.

Lavoie (1997) found that using a reflective writing exercise in conjunction with Concept Mapping revealed additional misconceptions and provided more information about students' understanding than did mapping alone. Kinchin, Hay, & Adams (2000) proposed that qualitative assessment of students' Concept Maps is more appropriate than quantitative methods when the intent is formative assessment of student learning. Edmondson & Smith (1996) used Concept Maps in several different ways in a veterinarian curriculum. Faculty members were able to identify student misconceptions and adjust teaching to address these.

Another set of studies stands out because they are all related to teacher development (e.g., Bolte, 1999; Butler, 2001). Abd-El-Khalick & BouJaoude (1997) used Concept Maps in conjunction with questionnaires and interviews to study in-service teachers' understanding of the structure, function, and development of their respective science disciplines. Beyerbach and Smith (1990) tracked pre-service teachers' knowledge about the processes of teaching and learning, using Concept Maps teachers constructed throughout their final year of the teacher preparation program. Ferry, Hedberg and Harper (1998) suggested that Concept Mapping helps pre-service teachers to organize their knowledge and curriculum content in integrated frameworks. Jones, Carter & Rua (1999) used teachers' pre- and post-course Concept Maps, along with journal reflections and portfolios, to examine professional growth as a result of changes in conceptual understanding of content and pedagogical knowledge.

In contrast, Lang & Olson (2000) and Winitzky & Kauchak (1995) looked at pre-service teacher knowledge and the effects of practical experience, found decreases in complexity and organization of knowledge from pre-or early course to post-course Concept Maps. Finally, Morine-Dershimer (1993) used pre- and post- course Concept Mapping to assess conceptual change in pre-service teachers. She developed a scoring technique that enabled her to identify patterns of change associated with particular features of the educational environment, which, she suggested would be useful for course or program evaluation.

3.1.2 Collaboration and Cooperative Learning

The benefits of collaboration in Concept Mapping have been noted in a number of studies. For example, Esiobu, & Soyibo (1995) compared groups using both Concept Mapping and V-diagramming, individually or in small groups, as a summarization or study strategy at the end of regular classroom instruction, with a control group that used neither tool. Both treatment groups did better than the control group as measured by multiple-choice-question achievement tests, and showed some advantage for cooperative group learning. Roth and Roychodury (1993) used Concepts Maps to examine the quality of students understanding.

Other researchers have found that collaboration does not appear to benefit students. For example, Chung, O'Neil, and Herl (1999) examined team processes that occurred as students jointly constructed a Concept Map over a computer network. The quality of constructed maps was not related to teamwork processes. In another study looking at collaborative map construction, Herl, O'Neil, Chung, & Schachter (1999) found no benefit for collaboration. In this study, researchers looked at two conditions for knowledge mapping. In one group, students collaborated over a network to construct group maps. In the other group, students worked individually to construct maps using information from web searches. Students in the individual mapping condition showed significant improvement in mapping scores over the course of a year. Students in the collaboration condition did not show change.

The nature of the interaction among participants appears to have an influence on whether or not effects of collaboration are positive (Chinn, O'Donnell & Jinks, 2002; Van Boxtel, Van Der Linden and Kanselaar, 1997, 2001). Collaborative Concept Mapping promoted more debate and reasoning in the interaction among students. Although outcome measures indicated no significance difference between the two conditions, frequency of elaborative episodes in the discourse of Concept Mapping students was positively correlated with individual learning outcomes. Among other benefits of Concept Mapping, Baroody & Bartels (2000) and Baroody & Coslick (1998) also noted that when used collaboratively, Concept Mapping promotes questioning, discussion, and debate. Interestingly, Stoyanova & Kommers (2002) found that synchronous collaboration with Concept Mapping "provoked a more intense collaboration", and resulted in "a more dense conceptual representation" than did mapping in distributed or mediated groups. Chiu, Huang & Chang (2000) also looked at group interaction during collaborative web-based Concept Mapping. Using a system for interaction analysis based on systems by Rachel Hertz-Lazarowitz (1990; 1992) and by Noreen Webb (1989; 1995), researchers found that, in particular, a type of high-level interaction called complex co-operation correlated most highly with mapping performance.

In closing this section, we describe a few other collaborative activities using Concept Maps, which exemplify a range of uses. For example, students can collaborate to indirectly support each other's learning. Cañas et al. (2001) described a computer-based collaboration environment, part of the CmapTools (Cañas, Hill Carff & Suri, 2003) software, designed to promote meaningful learning by means of a unique collaboration tool. The software allows students from distant schools to share claims (propositions) derived from their concept maps regarding any domain of knowledge being studied. Sharing takes place through the Knowledge Soup, a repository of propositions submitted by the students stored in a server. Propositions in the Soup that are found to be similar to those submitted by the student are displayed on the student's screen. He or she can use these propositions from other students to enhance his or her concept map. In addition, the student can question or criticize propositions submitted by other students, leading to a peer-review type of environment, where students themselves are responsible for the validity of the propositions in the Soup.

Cristea and Okamoto (2001) described a Concept-Mapping environment that is designed to support collaborative course authoring. The authors believe the mapping process can be useful for course designers because of its theoretical basis, which suggests mapping leads to additional creativity, as well as effective externalization and visualization of ideas.

Finally, Francisco, Nicoll and Trautmann (1998) reported on the use of Concept Maps in college level chemistry classes. In review sessions before exams, participants were provided with a relatively large map and asked to work together to integrate information from other Concept Maps or topics. By repeating this process throughout the course, students built a collaborative, integrated view of the chemistry topics covered in the course.

3.2 Assessment of Learning Using Concept Maps

Concept Maps can be used in formative or summative assessment procedures. In formative assessment, learners may be asked to make Concept Maps at various points in the learning process, and teachers can use these maps both to assess the learners understanding and to modify the curriculum. Summative assessment can be used at the end of an instructional unit to determine a learner's understanding of that unit, and to assign grades.

3.2.1 The Utility of Using Concept Maps for Assessment

Concept Maps constructed as ongoing evaluation of knowledge within a course, or across instruction in a discipline can be useful in demonstrating the changes that occur in a student's knowledge structure and the increasing complexity of knowledge structure that develops as students integrate new knowledge with existing knowledge. For example, Wallace & Mintzes (1990), described the use of Concept Maps as a way to demonstrate conceptual change. After instruction, all participants took a post-test, which included the same objective test taken as a pre-test and the construction of a Concept Map based on marine life zones. Results indicated that the experimental group showed small increases after instruction on the objective test. Other work on the utility of concept maps for assessment is presented in Markham & Mintzes (1994), Pearsall, Skipper & Mintzes (1997), and Martin, Mintzes & Clavijo (2000).

3.2.2. Methods of Scoring Concept Maps

The traditional method of Concept Map scoring was proposed by Novak and Gowin (1984), and is based on the components and structure of the Concept Map. Novak and Gowin's system assigns points for valid propositions (1 point each), levels of hierarchy (5 points for each level), number of branchings (1 point for each branch), cross-links (10 points for each valid cross-link), and specific examples (1 point for each example). The number of hierarchical levels addresses the degree of subsumption, the number of branchings indicates progressive differentiation, and the number of cross-links indicates the degree of integration of knowledge. This scoring technique has proven to be time-consuming, but it does give a great deal of information about the creator's knowledge structure. Some scoring techniques have been developed as extensions or variations of Novak and Gowin's system. For example, Mintzes and colleagues (e.g., Pearsall, Skipper & Mintzes, 1997) score the same components of the map but weigh them differently. Some researchers are pursuing the possibility of providing automated assessment of the structural components of Concept Maps (Luckie, 2001, NSF proposal).

Ruiz-Primo & Shavelson (1996) describe methods to compare a student's map to that of an expert. Expert maps may be constructed by a teacher, a domain expert or a group of teachers or domain experts. A comparison procedure must also be defined, and can range from propositional comparisons to holistic comparisons of structure. Computerized techniques can be used to simplify the comparison of maps, and this possibility has been explored by researchers at CRESST and other places (Chung, Herl, Klein, O'Neil & Schachter, 1997; Herl, O'Neil, Chung, Dennis & Lee, 1997; O'Neil & Klein, 1997). These automated scoring systems are typically based on propositional matching within limited sets of concepts and linking phrases. Holistic or structural comparisons are more difficult to automate, as they often require human judgment.

Some researchers have experimented with the combination of methods based on components, and methods based on comparison to a criterion (e.g., "expert") map. One example of this approach is to use traditional component-based scoring combined with some comparison to a criterion map, by assigning more weight to propositions that were considered to be critical by experts. Rye & Rubba (2002) reported such a Concept Map scoring system that was based on components, but which used an expert map to weigh propositions in the student maps.

Two major concerns have arisen regarding scoring methods for Concept Maps. The first is that traditional methods such as those based on Novak and Gowin (1984) are time-consuming and require the input of an expert, either in terms of judging the validity and importance of map components, or in the construction of a criterion map. The second issue is concerned with psychometric properties of Concept Maps as an assessment tool, and pertains to the reliability and validity of Concept Map scores. This issue will be discussed in the next section

The first concern has been addressed in at least two ways: the development of computerized scoring methods and the development of simplified map scoring techniques (e.g., Chung, Herl, Klein, O'Neil & Schachter, 1997; Herl et al., 1997; O'Neil et al., 1997; Luckie, 2001). An example of a simplified Concept Map scoring scheme is provided by Shaka & Bitner (1996), which uses Novak and Gowin's (1984) scoring scheme as a starting point, but provide simplified analysis of important map characteristics. In their approach, several map properties including propositions, branches, hierarchies, examples, cross-links and others are given a rating from 0 to 4, rather than being counted or characterized. This kind of simplification in scoring is probably typical of those utilized in Concept Map assessments. Another alternative that was proposed by Kinchin, Hay & Adams (2000), is to analyze maps in terms of their overall structure rather than in terms of a detailed analysis of concepts, links and propositions.

3.2.3 Reliability and Validity of Concept Maps for Assessment

Issues of reliability and validity of concept maps as assessment tools are integrally related to the concept map task and to the scoring system used (Ruiz-Primo & Shavelson, 1996). Traditionally, reliability issues related to the measurement of learning have not been concerned with consistency of scores over time (i.e., test-retest reliability) since actual knowledge is expected to change. Rather, the focus should be on inter-rater reliability (do people scoring the maps agree), and with the internal reliability of the measure. For example, Liu & Hinchey (1996), found relatively low correlations among different component scores in Novak and Gowin's (1984) scoring system. However, the component scores for propositions, levels of hierarchy, cross-links, and examples may actually be measurements of different aspects of the structure and organization of knowledge. A variety of conclusions have been drawn relative to reliability measures, including that they are "reasonable" (Shavelson & Ruiz-Primo, 2000; West et al., 2000), better for proposition-based scores than for structural scores (Shavelson & Ruiz-Primo, 2000; Herl et al., 1999), and better as raters become more experienced (West et al. 2000).

Concerns about validity have primarily focused on concurrent validity and construct validity. Concept maps have face validity to the extent that they directly represent Ausubel's components of meaningful learning: subsumption, progressive differentiation, and integration of knowledge. Concurrent validity has been demonstrated in numerous experiments in which concept map scores have been demonstrated to change over the course of instruction (Martin et al., 2000; Pearsall et al., 1997; Wallace & Mintzes, 1990), or to differ among groups known to differ in their degree of knowledge

(Markham & Mintzes, 1994; West et al., 2000). Many of these studies have been discussed in previous sections.

Construct validity is a different concern, which refers to the extent to which concept maps correlate with other measures of meaningful learning. It has often been suggested that concept maps measure different aspects of knowledge than traditional assessment techniques which do not measure meaningful learning; thus it is not surprising to find moderate or low correlations with some other types of assessments (Novak, Gowin & Johansen, 1983). Shavelson & Ruiz-Primo (2000) suggested that scores gleaned from concept maps are moderately correlated with traditional assessments (average $r = 0.50$), which demonstrates that concept map assessments measure something that is related, but not identical, to traditional assessments. West et al. (2000) also suggested that the correlation of concept map scores with standardized exams for medical students is moderately high, with the highest correlation for the map component of specific examples.

A related concern is predictive validity, whether concept map scores can be used to predict performance on skills that would seem to be related. Although the degree to which concept map scores can predict other performance scores is necessarily variable, some researchers have found relatively high correlations with some skills. Rice, Ryan & Samson (1998), designed a map scoring system that was based upon propositions that were assigned points if they contained correct propositional information that appeared on standardized state and national assessments. This type of scoring system resulted in high predictive validity, for these national achievement measures.

Research by McClure, Sonak & Suen (1999), investigated the relationships between map scoring method and measures of reliability and validity. Several different scoring methods were evaluated, including holistic assessments, assessments based on the correctness of individual propositions, and assessments based on structural components similar to those proposed by Novak and Gowin. Inter-rater reliability varied for the scoring methods, with the best results for propositional-based methods. Validity of map scores was assessed by comparing student-constructed maps with a master or expert map, through the use of techniques assessing the neighborhood or interconnectedness of concepts. The question addressed was whether the map score was an assessment of changes in student knowledge. In nearly all cases, concept map scoring techniques resulted in significant correlations between student maps and the master map. The best technique, both in terms of inter-rater reliability and validity, was based on propositional analysis of the concept map. Structural and holistic measurements appeared to be more problematic in terms of evaluation and matching between maps.

Increasing interest in the use of concept maps for assessment is likely to generate more interest in the development of computer scoring techniques and better assessment of the reliability and validity of concept map scoring in general. The use of large-scale automated scoring procedures will require further elaboration and testing of map scoring techniques. While proposition-based methods are the easiest to generate and to match across maps, these methods miss some of the most important structural characteristics of Concept Maps and should be applied with caution.

In previous sections we have presented a review of studies that employed Concept Maps as measures of conceptual change. We have described the types of scoring systems that have been used for Concept Maps (Ruiz-Primo & Shavelson, 1996), including traditional component-based measures such as Novak & Gowin (1984), methods based on comparison to a criterion or expert map, and methods which combine component-based and criterion-based assessment. These methods are often time-consuming and require human judgment, thus alternative simplified scoring schemes are often used. We have also addressed the reliability and validity of Concept Maps. These measures suggest that Concept Maps provide a different measure of abilities and knowledge than traditional assessment techniques. In general, the more specific the measure, the better the reliability and validity. Reliability and validity measures indicate that Concept Maps fall within acceptable ranges from the viewpoint of psychometrics (e.g., West et al; 2000; Shavelson & Ruiz-Primo, 2000).

In the following section, we will address other types of uses of Concept Maps, specifically those in which learners do not actively construct Concept Maps for either learning or assessment, but rather are presented with a pre-constructed map. The pre-constructed map may serve several purposes – as a scaffold for learning that is provided by the instructor, as an organizer for a course or curriculum that is presented to the student as a learning guide, or as a navigation guide in hypermedia.

3.3 Uses of Concept Maps to Organize and Present Information

This section reviews the uses of concept maps and related representations as advance organizers, as aids for course and curriculum development, and as a means to provide navigation support in hypertext. These uses are not completely independent of applications as learning and teaching tools, as in many cases maps might have been used in the classroom as an advance organizer for lectures.

3.3.1 Concept Maps as "Advance Organizers"

Ausubel (Ausubel, 1968; Ausubel, Novak, & Hanesian, 1978) advocated the use of "advance organizers" to foster meaningful learning. Advance organizers are global overviews of the material that is to be learned. Ausubel suggested that advance organizers foster meaningful learning by:

- Prompting the learner regarding pre-existing superordinate concepts that are already in the student's cognitive structure, and
- Providing a context of the most general concepts into which the student can incorporate progressively differentiated details.

In theory, advance organizers are most effective if they make explicit the relationships among learned concepts that learners already know, thus providing a structure into which the new concepts can be integrated.

A Concept Map can be utilized as an advance organizer (Novak & Gowin, 1984; Novak, 1998; Willerman & MacHarg, 1991). Advance organizer Concept Maps might be constructed by teachers or other experts. The Concept Map advance organizers can then be used in various ways as part of the classroom experience. They might be presented at the beginning of a textbook chapter or other instructional unit, or used as a guide for a lecture that is presented in a class. They might be used to present an overview of multimedia, with links to instructional materials associated with different topics. They have been used as lecture overheads, and as post-organizers for materials. Lambiotte, Dansereau, Cross & Reynolds (1989) suggested that “knowledge maps” (closely related to Concept Maps) might be used as an advance organizer for lectures, and that students might benefit from the assistance of the instructor in the interpretation of the map.

Coffey & Cañas (2003) describe a prototype Learning Environment Organizer (LEO) that can be used to build graphical course representations for computer-mediated instruction. LEO is being integrated into the CmapTools suite (Cañas, Hill, Carff & Suri, 2003). An Organizer can be used to represent the topics in a course, their sequence in terms of prerequisite relationships, additional explanatory information about the relationships among them, and links to pertinent instructional resources. An Organizer is comprised of a focus and context view and provides capabilities to show or hide individual parts. Using LEO, instructional designers can specify any of several completion criteria for the topics. For course designers, LEO serves as a meta-cognitive tool that fosters reflection on courseware design. The organizer is used by the students to identify and access instructional content that is most relevant to their needs and current progress. For students, the Organizer servers as an advance organizer in the sense described by Ausubel (1968). It is envisioned that Organizers will be used in face-to-face courses, in hybrid courses, and in distance learning offerings.

3.3.2 Concept Maps for Course or Curriculum Development

Novak (1998) suggests that using Concept Maps in planning a curriculum or instruction on a specific topic helps to make the instruction “conceptually transparent” to students. When Concept Maps are developed at the course or curriculum level, it is often desirable to organize them. This involves creating a global “macro map” which shows the main topics and their interrelationships, and more detailed “micro maps," which show more specific details for a particular portion of the instructional material. Concept Maps arranged in this way avoid some of the difficulties that are associated with processing large expert maps, or maps that attempt to cover too many focus questions or topics.

An example of an advance organizer for a college-level course has been implemented by Arguea & Cañas (1998) who developed a set of Concept Maps and associated resources that are used in a class on quantitative methods in business. The Concept Maps detail the use of applied statistics at the graduate level. Students use them as an adjunct rather than a replacement to in-class learning and assignments.

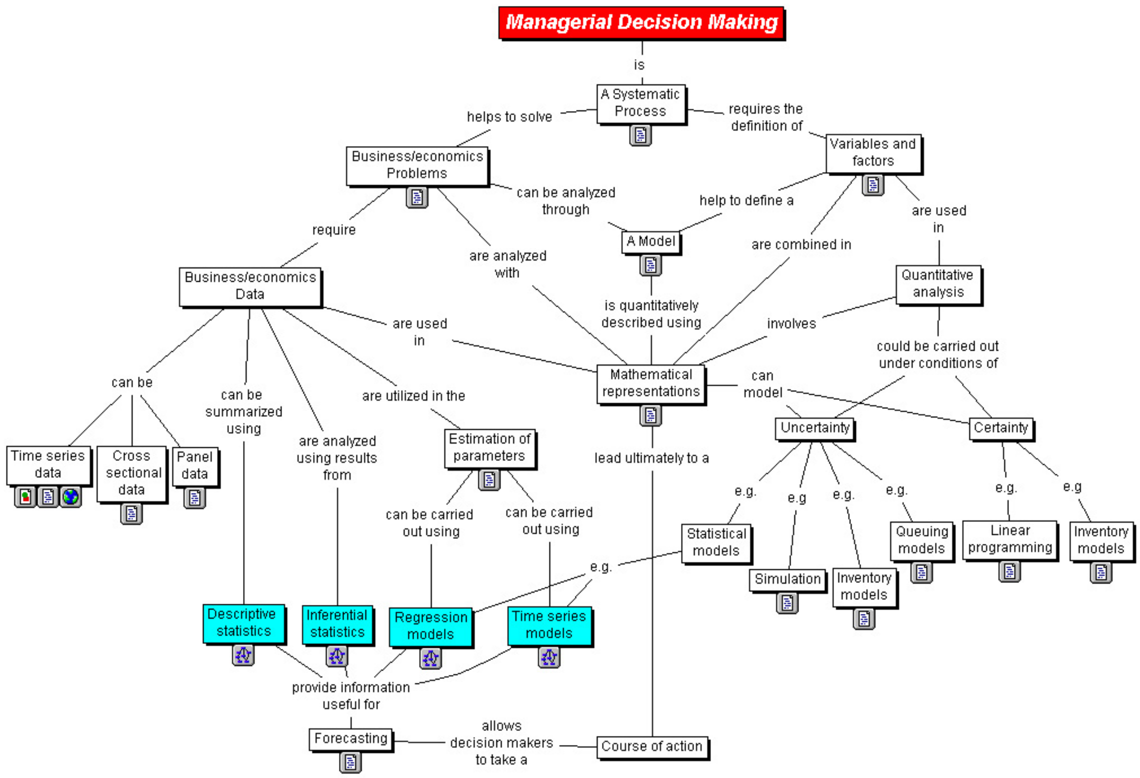

Figure 5. Top Level Map for a Course in Managerial Decision Making

Figure 5 illustrates the top-level map for the course. The map contains basic concepts of the course such as the ideas of mathematical modeling of business problems, the sorts of statistical analyses that can be applied to the decision-making process, the distinction between making decisions under conditions of certainty versus uncertainty, etc. The fundamental notion of the creation of statistical models that appears in the top-level map is expanded into a more detailed map that is illustrated in Figure 6. This structure leads to a hierarchically ordered collection of Concept Maps.

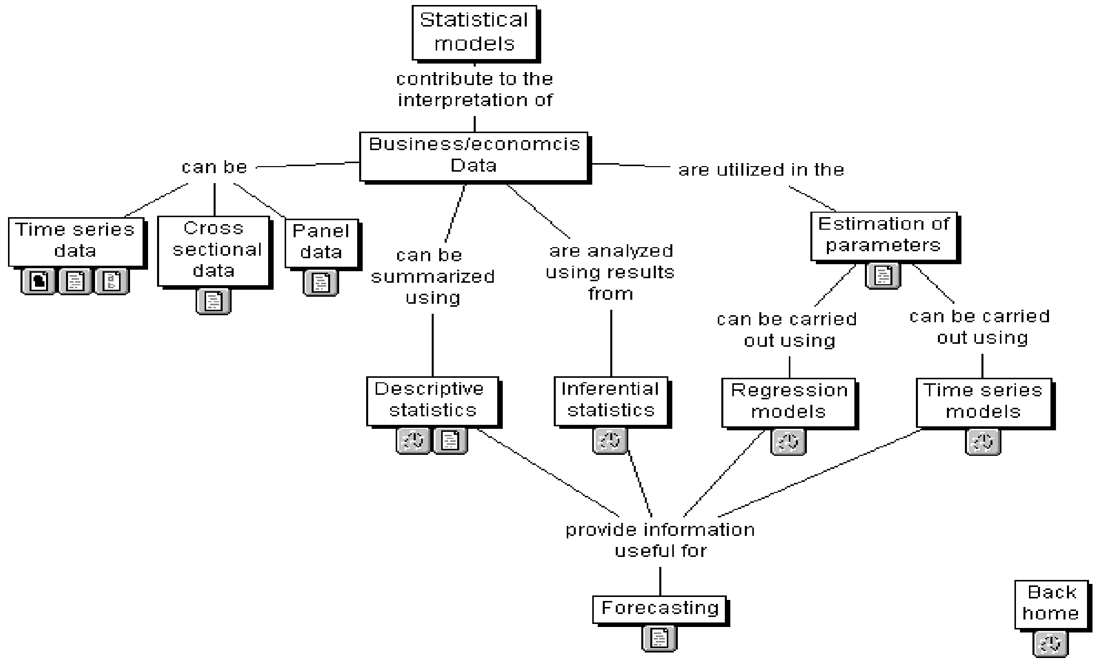

Figure 6. A Detailed Map pertaining to Statistical Models

Cristea & Okamoto (2001) described a Concept Mapping environment that was designed to support collaborative course authoring. Guimaraes, Chambel, and Bidarra (2000) used "cognitive maps" which were very similar to Mind Maps, to encourage students to interactively create a hypermedia production. Edmondson & Smith (1996) reported on the use of Concept Maps in an eight-week course where they were used by the instructor in the classroom as advance organizers and to illustrate relationships among ideas. Daley (1996) described the use of Concept Maps in individual courses, as a means to changing curriculum in nursing education. Concept Maps were created from course materials, and from interviews of student and instructors.

The semi-hierarchical organization of maps may be useful in terms of determining sequencing of materials, with meaningful learning more likely to occur if higher level, more inclusive concepts are presented early in instruction. Edmondson (1994; 1995) reported on the use of Concept Maps to describe the structure of courses in an interdisciplinary veterinary curriculum (see Figure 7). Concept Maps were used at several levels, including curriculum, foundation courses, lectures, labs and individual case studies. The curriculum rework required faculty to "reconceptualize" the subject matter in a way that avoided redundancy across various fields. Concept Mapping was used as a way of developing representations of the entire veterinary curriculum, the planned courses within the curriculum, and case-based exercises within the courses. The process of developing the curriculum involved a collaboration of faculty and students. Initially the goals and broad themes were developed by the entire faculty.

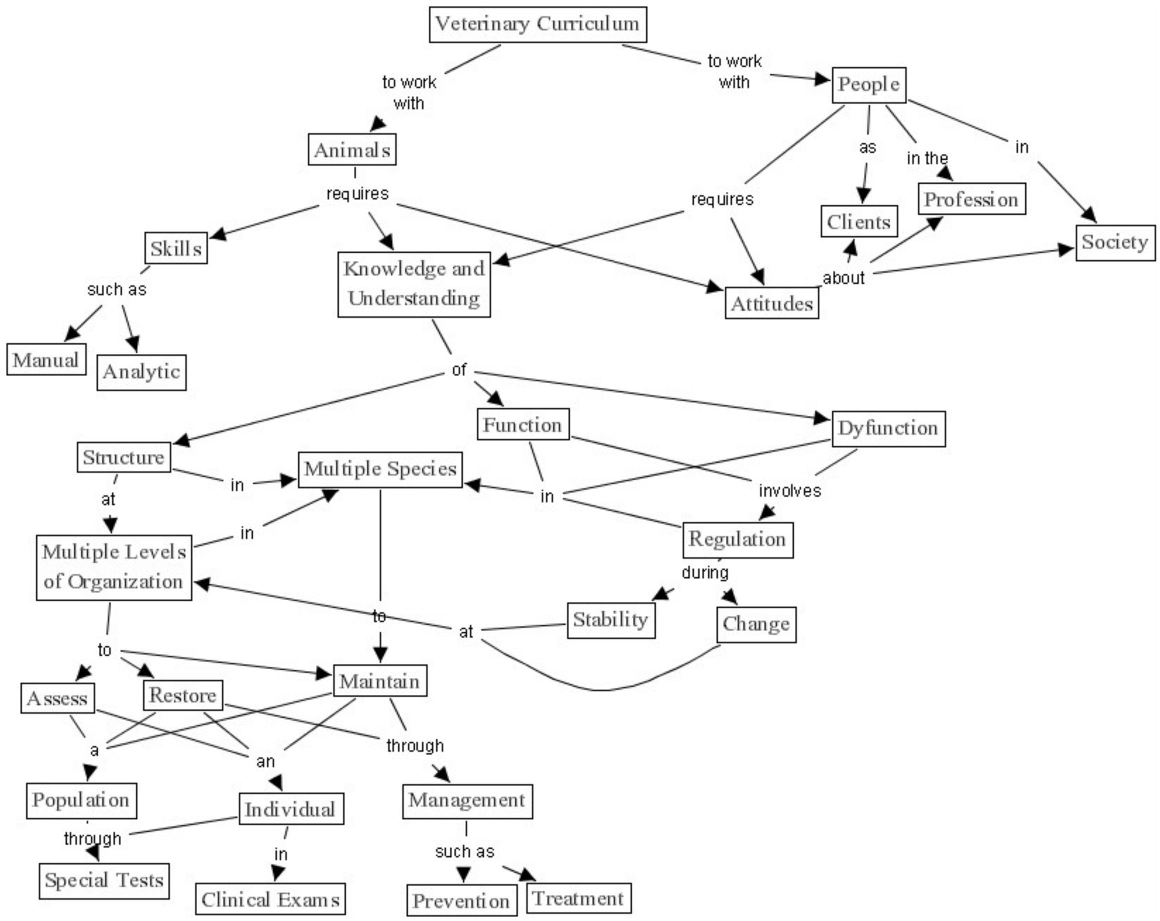

Figure 7. Top Level Curriculum Map developed by Edmondson and colleagues.

3.3.3 Use of Concept Maps for Navigation Support

There has been widespread interest in various graphical and mapping systems for hypermedia. In general, these maps may be referred to as navigation maps or as graphical browsers. Preliminary applications and demonstrations indicate that using Concept Maps for navigation may help people find topics more easily (Carnot, Dunn, Cañas, Baker & Bense, 1999; Carnot, Dunn, Cañas, Muldoon & Brigham, 2000). However, recent research has suggested that such use of navigational maps does not cause changes in knowledge structures (Nilson & Mayer, 2002). As we have seen in other types of educational applications, the use of concept maps for learning while navigating requires active processing and deliberation about the information provided. While often not engendering the active processing needed for learning, navigational tools in the form of concept maps and related representations can at a minimum provide easier, less frustrating access to information.

Researchers at Texas Christain University have compared the use of "knowledge hypermaps" to traditional hypertext (Reynolds & Dansereau, 1990; Reynolds, Patterson, Skaggs, & Dansereau, 1991). Participants were asked to find answers to domain-related questions and were tested with cued recall two days later. Participants viewed the knowledge hypermaps positively and were less frustrated with them. In a second study, Reynolds, Patterson, Skaggs & Dansereau (1991) combined the use of knowledge hypermaps with scripted cooperation (in which participants are assigned roles and tasks to perform.) Navigators using knowledge hypermaps performed better on recall tests than navigators using text. More frustration was reported by navigators than by pilots, and more frustration was expressed for text conditions than for knowledge hypermap conditions.

Hall (1997) used hypermaps without linking terms (thus they were not knowledge maps) to organize information for use in class and experiments. Participants reported that they enjoyed using the hypermaps, conducted broader searches of topics organized by hypermaps, and expressed less frustration than students using topic lists. In another study, Hall, Balestra and Davis (2000), participants were randomly assigned into hypermap and list groups. The students in the hypermap group studied hypermaps for thirty minutes, took a quiz consisting of 15 multiple choice items, and completed a questionnaire on their reactions. Participants reported that the hypermaps were helpful in studying and learning the information, though there was not a statistically significant difference in quiz scores.

Jonassen & Wang (1993) reported studies in which participants navigated a hypertext knowledge base structured with a semantic network. A graphical browser was constructed which took the form of interconnected non-hierarchical semantic networks. The semantic structure took the form of a semantic network that was constructed by an expert, and was based on the Hypercard version of the book. Concepts were interconnected with meaningful links. The hypertext contained 75 major concept nodes, 240 screens, and 1167 links. Participants could click on the concepts to navigate through the hypertext.

Jonassen & Wang's (1993) results indicate that simply providing a graphical browser as a navigation tool to participants may not improve their recall of the materials or their knowledge about the relationships among concepts. Rather, it seems that participants have to be encouraged to actively process the information they are viewing, and to think in terms of meaningful relationships. It is not enough to simply present the structural information to people. Some training or incentive on the part of the learner to use the maps to learn about relationships appears to be required.

Participants first were given time to examine the hypertext thoroughly and were to examine it until they had seen the entire document. They were then asked to find the answers to ten questions by locating the node that contained the answer in the most direct way. Participants in the high prior knowledge condition answered an approximately equal number of questions, regardless of whether there was a navigational aid and the type of navigational aid. Participants with low prior knowledge performed better when some type of navigational aid was provided, with a small advantage for spatial maps over content lists. Use of maps enabled non-knowledgeable participants to perform as well as knowledgeable students on time taken to answer questions, the number and the number of questions answered.

Carnot et al. (2001) conducted a study that compared browsers based on a concept map-based interface to a World Wide Web page-based interface to determine ease in finding information necessary to answer a series of search questions. Users differed in the amount of concept map training they received and the type of learner they tended to be (meaningful vs. rote learners). The results indicated that the concept map-based interface resulted in better search performance for all learners although this difference was most pronounced for meaningful learners. Training in concept map construction appeared to have no more effect on search performance using the concept map-based interface, than control conditions. Taken together, the results suggest that organizing information via a concept map-based interface leads to more accurate search performance than the typically used web page-based browser. Figure 8 presents a top-level Concept Map that was used in the study. The icons under the concepts in the map link to the content that was searched.

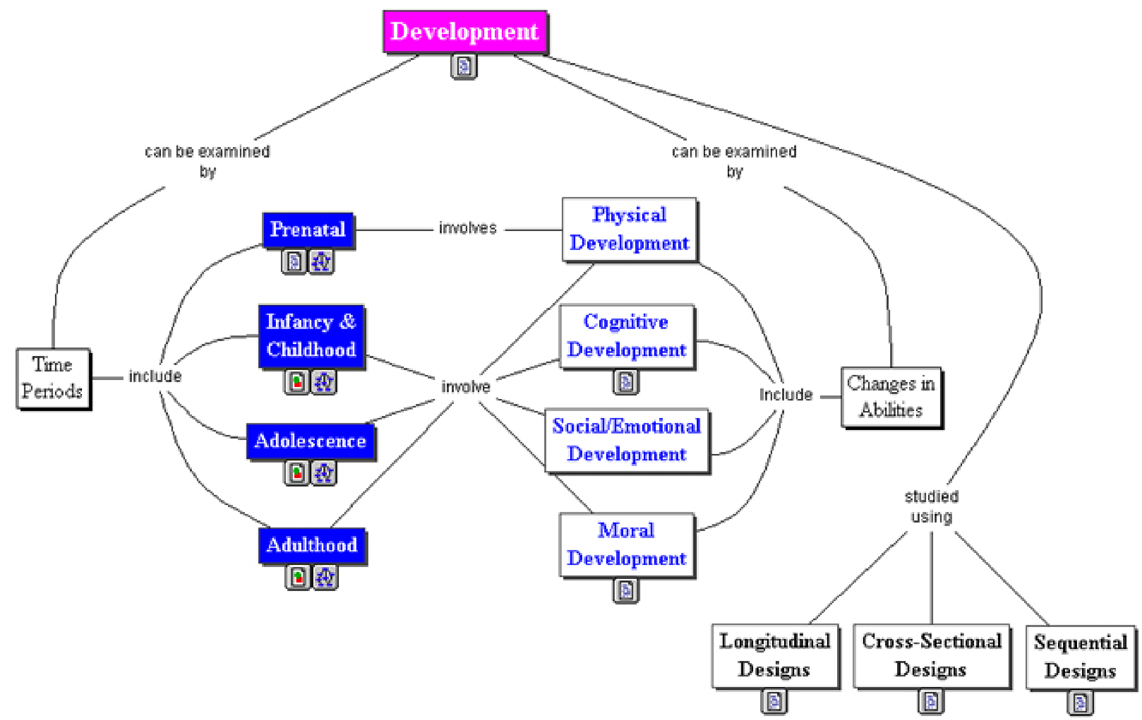

Figure 8. Example of Graphical Browser Screen from Carnot et al. 2001

McDonald and Stevenson (1998) described a study in which 36 participants were randomly assigned to use one of three navigational conditions: a spatial map, a contents list or no aid. Spatial maps were simply graphical diagrams of the main topics of the hypertext. The same main topics were used in the contents list. In the No Aid condition, participants used key words to navigate through the document. In addition, participants were divided into high and low prior knowledge groups on the basis of pretests.

Collaborative work between the IHMC and Center for Mars Exploration at NASA Ames Research Center led to the creation of "Return to Mars 2001," a large-scale multimedia containing many digital resources pertaining to Mars exploration (Briggs et al., 2001; available at http://cmex.coginst.uwf.edu). The goal of this work was to utilize Concept Maps as the organizing factor for the collection, which included a digital atlas, a gallery of images of Mars, numerous digital videos, and close to one hundred Concept Maps. The system has also been widely distributed on a CD to schools nationwide. The Concept Map in Figure 2 of this report is drawn from that Concept Map collection.

Nilsson and Mayer (2002) used a 150 page hypertext to explore the effects of graphical organizers. Results indicated that participants in the Map Group were initially more effective in navigation, but that they did not continue to improve over time. Evaluation of their navigation strategy showed that they tended to use only one or two of the available hierarchies to answer their questions. Participants in the No Map Group appeared to more actively use all of the hierarchical structures and showed greater improvement in navigation performance over time, providing some support for the requirement for active inquiry and constructiveness in learning.

Nilsson and Mayer (2002) did not use navigable maps in their experiments. Their results suggested the need to distinguish between maps for navigation and maps for learning, and the desirability of designing maps for specific purposes. Another important implication from their study is the need to actively engage learners. Simply providing a map that gives easy access to information in initial stages is not enough to promote knowledge of the structuring of materials, or even knowledge of the content of the maps. As we have found in numerous other studies, active processing by learners is required for maps to be most meaningful and useful. The task requirements of navigation may not promote the kinds of meaningful processing necessary for learning.

3.4. Evidence of Effectiveness of Concept Mapping for Education

Concept Mapping had its roots in education, and education and learning probably still constitute the bulk of its use. Hence, the purpose of this section is to review a number of studies of the effectiveness of Concept Mapping as a learning tool. The issue is not *whether or not* Concept Mapping enhances learning. Like any other tool, the effectiveness of Concept Mapping depends on how it is used and the conditions in which it is used. There is no doubt that Concept Mapping *can* enhance learning. An earlier review of the educational effectiveness of Concept Mapping (Horton et al., 1993) concluded that Concept Mapping can have educational benefits that range from what can only be described as huge, all the way to having negative effects (i.e., when some alternative instructional intervention produced learning effects greater than Concept Mapping), although the great majority of the studies reviewed showed differing degrees of positive effect for Concept Mapping. This section will contain a brief overview of the fourteen studies we examined. Appendix B contains details on the studies.

3.4.1 Studies with Random Assignment of Learners to Conditions

The purpose of a study by Esiobu & Soyibo (1995) was to test effects of Concept Mapping and Vee diagramming in different forms of instruction, e.g., small group vs. large group, cooperative, vs. competitive. The study took place in Nigeria and involved secondary school students (said to be equivalent to tenth grade high school students in the United States). The subject matter was ecology and genetics. The results were that students in the treatment conditions greatly outscored those in the controls in all learning conditions. There appear to have been some general benefits of cooperation as well. This is one of the strongest demonstrations of the educational effectiveness of Concept Mapping to be found.

Schmid & Telaro (1990) sought to test the effectiveness of Concept Mapping on high school biology achievement and to assess this by student academic ability level. The study was conducted in Montreal, Canada and involved students at levels "4 and 5" of the Canadian system. The subject matter was a unit of a biology course on the nervous system. The experimental design combined treatment and control crossed with three levels of Academic Ability (high, medium, and low). The results indicated that the helpfulness of Concept Mapping increased as groups went from high to medium to low ability. The authors speculate that Concept Mapping helps low ability students to a greater degree because it requires them to take an organized and deliberative approach to learning, which higher ability students likely do anyway.

The goal of a study by Bascones & Novak (1985) was to test the effect of Concept Mapping on students' problem solving in physics. The teaching process used in this study was based on Ausubel's (1968) theory of meaningful learning. The course was a required physics course taught throughout Venezuela. The design involved two groups. The treatment group had general-to-specific orderings of content and routine Concept Mapping exercises, while the control group had traditional instructional methods. The results showed large effects in favor of the treatment group on every test administration and at all ability levels. The results of this study clearly present a strong statement for the benefit of the instruction that was based on Ausubel's (1968) learning theory and some sort of utilization of Concept Maps. Unfortunately, the nature of this instruction is not fully described.

3.4.2 Studies in which Classes were Randomly Assigned to Conditions

Pankratius (1990) sought to test if Concept Mapping, and especially the *amount* of Concept Mapping, would affect achievement in physics problem solving. The main variable was the amount of Concept Mapping practice/experience the students were engaged in. One treatment group created Concept maps at the beginning of a unit and continuing to improve them throughout, a second treatment group made Concept Maps once at the end of a unit. A control group did not make Concept Maps. The results showed statistically significant differences, with both treatments performing better than the control, and periodic Concept Mapping being more effective than Concept Mapping just at the end of the unit.

A study by Czerniak & Haney (1998) was designed to test if the addition of Concept Mapping to instruction in a physical science course would improve achievement, reduce anxiety toward physical science, and reduce anxiety about teaching physical science at the elementary school level. The results showed that Concept Mapping increased achievement, decreased anxiety for learning physical science, and decreased general (trait) anxiety. Results did not indicate an increase self-efficacy for teaching physical science.

The goal of Jegede, Alaiyemola & Okebukola (1990) was to test whether the addition of Concept Mapping to instruction would aid achievement and reduce anxiety (toward biology subject matter). The study was conducted in Nigeria, with students who were the American-equivalent of grade ten. The results were dramatically in favor of Concept Mapping. There were positive effects in favor of the Concept Mappers in both achievement and for anxiety reduction.

3.4.3 Studies that Utilized Extant Methods of Instruction

The goal of a study by Nicoll, Francisco & Nakhleh (2001) was to investigate the value of using Concept Mapping in general chemistry and, more particularly, to see if Concept Mapping would produce a more interconnected knowledge base in students, compared to ordinary instruction. The results showed that the Concept Mapping group knew more concepts (49 vs. 38), more linking relationships (69.9 vs. 46.2), more "useful" linking relationships (55 vs. 34.6), and had no more erroneous linking relationships than the non-Concept Mapping students. Despite some design flaws (e.g., non-random assignment, and more high school chemistry experience among the treatment group) these finding are very impressive for Concept Mapping, as it relates to the development of an interconnected knowledge base.

3.4.4 Studies in which an Alternative Educational Intervention was compared to Concept Mapping

A study by Spaulding (1989) addressed the effects of Concept Mapping versus "concept defining" on learning achievement in biology and chemistry. The results showed no differences between Concept Mappers and Definers. There was also no differential effect for chemistry vs. biology. The statistical interactions indicated that lower ability students performed better with Concept Mapping, and higher ability students performed better when just defining the concepts. In another study that found no treatment effect, Lehman, Carter & Kahle (1985) tested the effects of Concept Mapping (with Vee diagraming) vs. "outlining" on improving achievement in a biology course. No statistically significant differences were found in the study.

Zittle (2002) set out to determine the relative effectiveness in producing analogical transfer of studying text, studying a completed Concept Map, or filling in a blank, but structured Concept Map. The study involved three groups: one that studied text; a second that studied Concept Maps; and a third that selected concepts to fill in Concept Maps. The dependent variable was the number of hints required for solving a set of problems. The text and Concept Map groups were nearly identical (requiring 7.3 vs. 6.2 hints respectively). The group that filled in the Concept Maps required only half as many hints (3.4).

A study by Chang, Sung & Chen (2001) sought to test the benefits for learning of three different kinds of uses of Concept Maps. The design involved four conditions, one control and three experimental, and a pre- and posttest. Twice per week for four weeks, students read one of the science articles and studied it under one of the four conditions. In the Map Generation group, students constructed a Concept Map for the material from scratch. In the Map Correction group, students were given an "expert-generated" Concept Map for the material, in which some errors had been introduced. Students were to find and correct these errors. In the Scaffold-Fading group, students were progressively weaned from pre-constructed Concept Maps. The control group received no adjuncts at all, just the original text to read and study. The results showed that "the map-correction group did better on the (comprehension) post-test than the map-generation and control did, and the differences among the scaffold-fading, map-generation, and control group were not significant" (p 15).

3.4.5 Studies that compared Concept Maps with other Forms of Learning Material

The goal of Hall & O'Donnell (1996) was to test free recall memory of material presented as either text or as a Knowledge Map. The results were that the Knowledge Mapping group showed better recall for both superordinate and subordinate materials.

The purpose of a study by Moreland, Dansereau & Chmielewski (1997) was to test the effect on learning from Concept Mapping versus using text annotations, which are learner-generated enhancements of learning materials, including underlining, marginal notes, etc. These have found to be effective for learning in other studies, but here they were used for learning with Knowledge Maps (Knowledge Maps are very similar to Concept Maps except for more restriction on the nature of links and less restriction on the content of nodes in K-Mapping). There was no statistically significant difference on recall between the mapping condition and the text condition, although a difference in favor of the mapping group approached significance ($p<.08$).

Rewey et al. (1989) tested the effects on learning of the format of supplemental materials, i.e., "knowledge mapping" vs. text. vs. no supplement, across three styles of instruction: cooperative learning vs. cooperative teaching vs. individual study. Two major results were that the Knowledge Mapping groups did not outperform the other supplement groups, although trends in that direction were apparent. Neither did the cooperative groups outperform the students who worked alone.

4. Applications in Business and Government Settings

4.1 Concept-Mapping as a Technique for Eliciting Knowledge

In this section we summarize reports on empirical studies of the use of Concept-Mapping as a technique for knowledge elicitation (KE). This topic overlaps with the educational uses of Concept Maps. Student/learners can be regarded as individuals who fall toward the novice end of the continuum of novice-apprentice-journeyman-expert, and their knowledge (represented as Concept Maps) is sometimes compared to that of experts. A number of attempts have been made to create software that facilitates the process of eliciting knowledge from experts, and Concept Maps have been used as knowledge elicitation tools in several of these systems.

We review some studies that used diagrams that are marginally Concept Map-like in empirical studies of expertise. The prime example is the research on expert-novice differences that has used "Pathfinder" associative networks. These express concepts as nodes but relate concepts to one another according to a single type of link—semantic similarity or relatedness. Empirical evidence of the utility or effectiveness of such diagrams in KE can be taken as partial or tentative support for the general utility of conceptual diagrams in KE. The literature groups conveniently according to the main goal of the work:

- Using Concept Mapping tasks to reveal expert-novice differences.
- Evaluation of Concept Mapping as a method for Knowledge Elicitation (KE) with experts.
- Using Concept Mapping with domain experts to support the design of new technologies (e.g., interfaces).
- Using Concept Mapping as a method in Software-Assisted Knowledge Acquisition (SAKA).

4.1.1 Using Concept Mapping to Reveal Expert-Novice Differences.

Studies in the first category have the general aim of confirming basic claims about expert-novice differences as have been revealed in psychological research (knowledge extent, knowledge organization, large short-term and long-term memory for domain information, efficiency of information processing, depth of problem representation, and self-monitoring) (Glaser & Chi, 1988). Concept Maps created by experts and novices should have different semantic and structural features (e.g., number of concepts, number of links, number of clusters, etc.), which should reveal expert-novice differences, and also further differentiate more and less knowledgeable students.

Cummings and colleagues (Cummings et al., 1990; Martin et al., 1989) applied Concept Mapping to reveal differences in the knowledge structures of expert versus novice counselors with regard to their views about the process of change that occurs during and as a result of counseling, and their beliefs about the most important issues to consider. The expert Concept Maps included more concepts that fell at a "deep" level, i.e., pertaining to interpersonal interaction. The novice counselors produced Concept Maps having more concepts, but these tended to represent literal or superficial characteristics of the clients. The Authors argued that experts possess "schemas" of "deep-level" psychological principles that enable them to create Concept Maps having fewer concepts than those of the novices.

Mayfield, Kardash, & Kivlighan (1999; see also Kivlighan & Quigley, 1991) also applied Concept Mapping in an attempt to reveal differences in the knowledge structures of expert versus novice counselors. The results showed that novices were more likely than experts to place transcript statements into the same cluster if the statements occurred in close temporal proximity. In concert with Cummings et al. (1990), Mayfield et al. (1999) concluded that experts possess schemas that enable them to structure client information parsimoniously, in terms of reciprocal influences rather than linear causation. It is claimed that Concept Mapping can be used in counselor education and training by encouraging novices to break out of the tendency to deal with client information at a superficial level.

4.1.2 Using Concept Mapping With Domain Experts to Support the Design of New Technologies

McNeese and colleagues (McNeese et al., 1990; 1993; 1995) applied Concept Mapping in eliciting the knowledge of experts in service of design. Their work is one of the best exemplars to be found in the literature. McNeese et al. argued that there was a need for software tools that support collaborative design, and that the creation of such tools will depend on achieving an understanding of the design process. That understanding cannot be achieved by observation alone, but must be supplemented by a KE procedure such as Concept Mapping. According to McNeese et al., the Concept Mapping procedure could be used to elicit and represent the knowledge of domain practitioners and contribute to the design of new information technologies, such as decision support systems. The Concept Map would express the user's requirements, which could be used to shape the design of task structures.

They reported results from eight projects:

- Concept Mapping with USAF fighter pilots to capture pilots' decision making and strategies. This work contributed to the creation of the "Pilot's Associate" —an intelligent decision aid.
- Concept Mapping with USAF helicopter pilots, based on pilot complaints about workload, was used to aid in the complete redesign of the cockpit for a particular helicopter.
- Concept Mapping was used by an expert in aerospace engineering to create a general Conceptual design of crew stations for transatmospheric vehicles.
- Concept Mapping with seven human factors specialists (Aeronautical Systems Center) was aimed at describing the process of collaborative design. The Concept Maps revealed the importance of disagreements among team members concerning design elements, i.e., disagreements pointed to the design conflicts and tradeoffs.
- Concept Mapping was with workers at the Engineering Documents Branch of the USAF Aeronautical Systems Center. It was found that in-house expertise on engineering bibliotechnology was sometimes left unshared or unexploited. Results guided continuing efforts at improving the organization.

- A Design Advisory Group at the USAF Armstrong Laboratory was tasked with making recommendations for long-term improvements internal information management systems and procedures. The Group Concept Mapped a number of main topic areas (office tools, communications systems, laboratory tools, archiving systems, etc.). Survey results and the individual Concept Maps revealed the existing problems, an understanding of their nature, and some possible solutions.
- A team at the USAF Armstrong Laboratory was tasked to develop a computer aid that would allow users to learn about human factors issues in engineering design. Members of the design team created Concept Maps describing their effort and the issues and problems involved. Subsequently, team members collaborated in the creation of a Concept Map in which they compared their perspectives. Concept Maps of the individual team members revealed goal conflicts, entailing changes in existing procedures and the adoption of new procedures (e.g., the use of storyboards in the documentation of design changes).
- The USAF team was tasked with creating a "workbench" for the depiction of apparent motion phenomena. Two participants, one an expert in interface design and the other an expert in the psychophysics of apparent motion, collaborated to construct a Concept Map expressing the information they wanted the workbench to convey to users. The result was a description of the proposed system, expressed in a form that was compatible with the needs of the programmers.

The methods of Concept Mapping (and storyboarding) using white boards were consistently effective in eliciting expert knowledge. The methods were easy for all participants to learn, "virtually self-explanatory" (McNeese et al., 1995, p. 359). Storyboarding was effective in eliciting ideas for interface or display design, but it was most effective when building upon the knowledge that had been elicited in Concept Mapping. Participants reported that the Concept Mapping process was not only interesting and enjoyable, but also that it helped them clarify their own understanding of their work and how it might be improved. McNeese et al. argued that the Concept Mapping process helped the participants overcome their reticence and feel a sense of cohesiveness, cooperation, and mutual respect.

4.1.3 Evaluation of Concept Mapping as a Method for Knowledge Elicitation (KE) With Experts

Gordon & Gill (1989) and Graesser & Gordon (1991) investigated the use of conceptual graphs to represent knowledge in novices and experts. Gordon, et al. provided evidence of the representational validity of conceptual graphs by comparing the clustering of concepts in conceptual graphs to the clustering observed in protocols from think aloud problem solving sessions. This suggested that conceptual graphing can be used to improve explanatory text by pointing to incompletenesses. Gordon, Schmierer, & Gill (1993) compared the conceptual graphing technique to the use of explanatory text, to assess the materials in terms of facilitation of problem solving performance on test cases (in the domain of engineering, using students as participants). Students attempted to learn materials either from text or from a conceptual graph created on the basis of expert knowledge. The conceptual graph materials won out in terms of the learner's problem solving performance.

Thorsden (1991) assessed the relative strengths of Concept Mapping and the “Critical Decision Method” (CDM) of knowledge elicitation. The CDM is a KE procedure in which the participant (usually, a domain expert) is guided by specially-crafted probe questions in multi-pass retrospection on previously-encountered “tough cases” that challenged the participant’s expertise (Hoffman, Crandall, & Shadbolt, 1998). The relative strengths of Concept Mapping and CDM were evaluated in terms of type of knowledge elicited, uses in informing the process of display/interface design, and uses in informing the design of training programs for military tasks. Thordsen held that Concept Maps and CDM studies were complementary since Concept Maps were useful for the capture of global understandings and CDM was useful for attaining details of anomalous cases. The view that alternative KE methods can be combined and can be complementary is affirmed by other empirical studies and review articles (e.g., Hoffman et al., 1995).

Hoffman et al. (2000) compared a number of KE methods, including Concept Mapping, in a study of expertise in weather forecasting. Participants included two senior experts and the forecasting facility's Commanding Officer, who had considerable experience at hurricane forecasting and had written a Handbook on Tropical Forecasting. Results showed that an individual at the Senior Journeyman level or greater can analyze propositions in a Concept Map at a rate that is at least an order of magnitude faster than when using the traditional text document (the Local Forecasting Handbook).

4.1.4 Using Concept Mapping as a Method in Software-Assisted Knowledge Acquisition (SAKA)

The creation of intelligent systems often hinges on a collaborative modeling process in which domain experts and knowledge engineers work from the expert's natural language description of their knowledge to a representation of concepts and their relations, and then work from that to some form of inventory of the domain ontology (Ford & Bradshaw, 1993; Regoczei & Plantinga, 1987). The use of conceptual graphs, in general, in the knowledge elicitation process has been fairly widespread, beginning with the era of first-generation expert systems (See Dodson 1989; Regoczei & Hirst, 1988). Concept Maps can be used as “mediating representations” that bridge the gap between the ways experts informally describe their knowledge and formal or computable representations of that knowledge.

Taken as a general category, diagrams of many sorts have been used to aid in creating expert systems, including expert system interfaces (see Dodson, 1989). If Concept Maps in particular can represent experts’ domain knowledge, they should be useful in the creation of such things as interfaces, the knowledge bases in intelligent systems, and so on. Furthermore, Concept-Map representations should make it easier for people to understand what software is doing, so that the human can effectively and reliably communicate with the computer, i.e., the human and machine will be a “joint cognitive system.” Regoczei and colleagues (Regoczei & Hirst, 1988, 1992; Regoczei & Plantinga 1987) saw value in the process of conceptual graphing for the expert and knowledge engineer to collaboratively create representations of domain ontologies, and thereby serve to translate from the natural language the domain expert uses, to a form of representation that is compatible with that of intelligent (i.e., expert) systems.

Cañas, Leake, & Wilson (1999) reported on an effort to develop SAKA tools, using Concept Maps, for the purpose of knowledge preservation and re-use (knowledge management). Their demonstration placed Concept Mapping in a complementary role with Case-Based Reasoning (CBR), with the goal of leveraging cases to enrich the information presented in Concept Maps. Concept Mapping with domain experts (i.e., NASA - Ames design engineers) was used to create two sets of Concept Maps, one set describing different airplanes and the other describing the designs of components and the interrelations of components. Cañas et al. reported that the Process of designing components for new aircraft was supported by the Concept Map-CBR system because it aids the designers in their search for analogous past cases. Furthermore, it is argued, new designs can be developed by the manipulation of the Concept Maps describing previous designs and by the reliance on "suggestion list" of concepts and linking relations, composed from the corpus of existing Concept Maps and presented as menu options.

The use of Concept Maps to create navigable explanations of expert systems was demonstrated by Ford et al. (1993), who also introduced the idea that resources (e.g., repertory grids, video, graphics, and text) could be integrated into a Concept Map knowledge model, and that the use of Concept Maps to organize such resources can mitigate navigation problems. They further suggested that such a model of expert domain knowledge can serve as a training support tool insofar as the user can improve their own performance through their analysis of the domain model of the expert. What Ford et al. proposed is a facility that allows the user to assume an active role in the process of constructing his or her own explanation by freely navigating through the domain model.

Ford et al. (1991) created a knowledge acquisition (SAKA) system called ICONKAT (Integrated Constructivist Knowledge Acquisition Tool), for the design, construction, testing, and maintenance of knowledge bases and the collaborative creation of the explanation components for knowledge-based systems. The KE procedures supported by IKONCAT included Concept Mapping and a "repertory grid" (multidimensional scaling) procedure in which the domain concepts or categories (referred to as "elements") are assessed in terms of their value on a number of bi-polar dimensions (referred to as "constructs"). The concepts from the Concept Maps provide the elements for the repertory grid analysis. Constructs (dimensions) are elicited on the basis of the provided elements. The primary role for the task is to generate candidate procedural rules.

Ford et al. (1992; 1996) reported the successful application of this approach in the creation of an expert system. The Nuclear Cardiology Expert system (NUCES) was intended to assist non-expert cardiologists in the interpretation of radionuclide images of the heart. Ford et al. noted that the Concept Mapping procedure in ICONKAT used in the NUCES project included the important idiosyncratic knowledge ("personal constructs") of the expert. Through his experience the expert had discovered important and useful diagnostic cue configurations and had named them using visual metaphors such as “blue fingers,” “ice cream cones,” and “ballerina’s foot.” The kind of knowledge that was revealed by the Concept Mapping was critical to his practice, but is hardly the kind of knowledge found in textbook presentations.

Jeong et al. (1998) reported on a project that involved the use of Concept Mapping SAKA to support the process of teaching/learning and the creation of an intelligent tutor in the domain of cardiovascular medicine. Concept Maps were created on the basis of the domain expertise of the researchers. Jeong et al. reported that in the process of creating diagrams in this domain, both the Authors and their students relied on switching back and forth between anatomical and functional representations. The Authors claimed that use of the diagramming tool permits easy construction of knowledge bases and assessment of their completeness.

4.2 Concept Mapping for Knowledge Management

A growing body of literature on knowledge mapping as it pertains to knowledge management contains descriptions of attempts to map enterprise-wide relationships within an organization. These relationships pertain to the location and ownership of organizational knowledge, roles, expertise, and relationships among people, and the flows of knowledge within an organization. Kingston & Macintosh (2000) provide a good discussion of the basic ideas of knowledge management. They define knowledge management as:

> “. . . the identification and analysis of available and required knowledge assets and knowledge-asset related processes, and the subsequent planning and control of actions to develop both the assets and the processes so as to fulfill organizational objectives.” (p. 121).

They state that it is necessary to capture and represent knowledge, to make re-use possible through knowledge sharing, and to create a culture that fosters knowledge retention, sharing and reuse. They advocate multi-perspective knowledge modeling in which knowledge assets are represented as a collection of knowledge models with different representations appropriate to the various uses.

Kingston and Macintosh mention Unified Modeling Language (UML) with use-case diagrams (“who” knowledge) class diagrams (“what” knowledge) activity or state chart diagrams (“how” knowledge), collaboration diagrams and component diagrams as the multiple perspectives of the UML approach. They present a Concept Map-like diagram that describes the capabilities, rights and responsibilities of agents in an Ear, Nose, and Throat (ENT) department. This Concept Map is presented in Figure 9. It seems evident that any global, comprehensive model of an organization and its knowledges will necessarily include multiple representations of what can be heterogeneous types of knowledge. Concept Map representations are not panaceas in such applications, but they can be useful for brainstorming, capturing “big picture” knowledge from experts, and tying together various other representations.

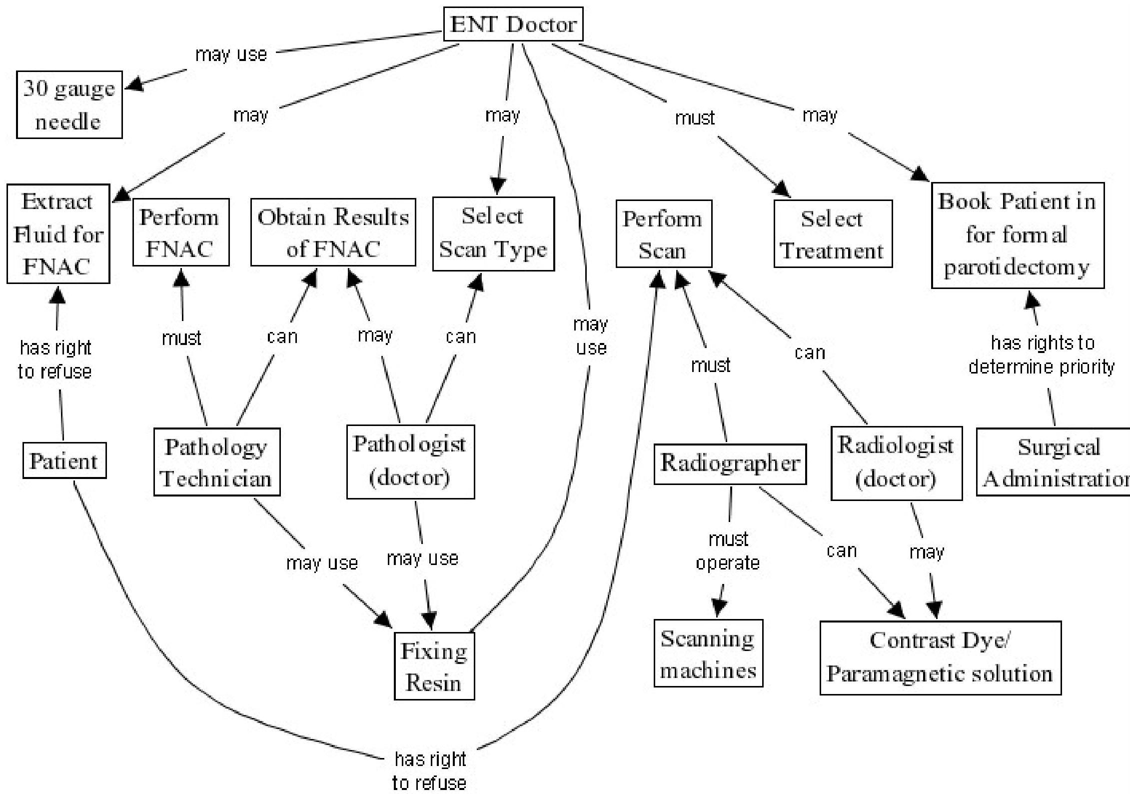

Figure 9. A Concept Map pertaining to People, Responsibilities and Activities in a Ear, Nose, and Throat Practice.

Vail (1999) drew a distinction between tacit or implicit knowledge and explicit knowledge in his paper on knowledge mapping. Vail described implicit models that reside in people as "mental models" of experience and skills, and that are difficult to communicate. He described explicit knowledge as that which can be communicated externally and represented in formal models, rules, and procedures. He described "knowledge maps" as a good way to share explicit knowledge and to make records of the people who hold implicit knowledge in a given area.

Vail provided an example of a good place to use knowledge management – to bridge the gap between the broader management function and the IT components of a business. He presented knowledge maps that integrate a variety of organizational concerns such as processes, strategies, customers, organizational structure and products. This is reminiscent of the multi-dimensional views espoused by Kingston & Macintosh (2000).

4.2.1 Brainstorming

Brainstorming is "a method for developing creative solutions to problems. It works by focusing on a problem, and then deliberately coming up with as many deliberately unusual solutions as possible and by pushing the ideas as far as possible" (Mind Tools, 2002). As described in the next paragraphs, graphical representations of ideas such as those afforded by Concept Maps are useful for brainstorming.

Citera et al. (1995) described the use of Concept Mapping to elicit and represent knowledge in order to identify how multidisciplinary teams can be more effectively supported with information technology. Their work involved interactive sessions in which the Concept Maps were built “on the fly.” The sessions included the expert, a Concept Mapper and a team of interviewers. Concept Maps were drawn on white boards. Each session was between one and three hours duration. A total of six Concept Maps were produced. A computer program named “Concept Interpreter” was used to analyze the Concept Maps.

Kremer & Gaines (1994) described a Concept Mapping tool named KMap, and a groupware Concept Mapping tool named Accord. The authors stated, very generally, that the idea behind both tools is to support the creation and communication of knowledge. They described a three-person group with no prior experience in Concept Mapping that used Accord to produce a Concept Map pertaining to the implications of introducing a Networking system into an organization. The group created a 35 node Concept Map in 90 minutes. While very clear in expressing the view that the brainstorming process was improved as a result of Concept-Mapping, the paper is rather weak in its description of the methods that were used. The authors described the capability of navigating from nodes in the Concept Maps to other Maps or associated documents. They cited the possibility of emulating the visual languages and graph-like appearance of other knowledge representations such as PERT diagrams, Petri nets, etc.

4.2.2 Knowledge Sharing

Dicheva, & Aroyo (2000) described what they characterized as an integrated approach to information handling and knowledge management in web-based, open-ended learning environments that utilize Concept Maps. Their approach seeks to lend support to both learners and instructors in information structuring and task-oriented processing and usage. They described Agent-based Information Management System (AIMS), a web-based tool for task-based information and performance support. A central part of AIMS is the use of Concept Maps to build domain ontologies. The Concept Maps are retained to serve as a graphical information visualization and navigation tool. The authors state that AIMS focuses on three important aspects of the information handling process: information structuring, information visualization, and a user centered approach.

Gordon (2002) described the creation of what he calls “Knowledge Structure Maps,” which are intended to present a visualization of a knowledge area, and to provide support for decision-making and information sharing. Gordon's work was conducted in conjunction with the Applied Knowledge Research Institute (AKRI), which provides knowledge structure mapping on a consultancy basis. The knowledge structure maps developed by AKRI typically do not have labeled links, but do show hierarchal structure and use cross-links. They often create relatively large maps to show overlapping areas of knowledge.

Knowledge structure mapping by AKRI has been conducted at British Aerospace. This knowledge-mapping project consisted of two people spending one week creating a large knowledge map on the topic of knowledge that was being shared with other companies, and its value. The map was evaluated to determine qualitative measures such as the complexity and importance of the knowledge elements and a characterization of the knowledge as more procedural or declarative. The map identified knowledge clusters and "high risk" knowledge (knowledge that should not be shared), and fostered a discussion among managers regarding what knowledge was essential to the company and what was not. Gordon stated that this sort of knowledge mapping creates a visible framework that fosters knowledge management. Gordon also claimed that if companies consistently used such techniques, managers would be able to benefit from a common view of knowledge assets. Knowledge Structure Maps are said to have benefits in terms of improving understanding of knowledge, and assessing its value and extent.

Work performed by IHMC researchers at one of the intelligence agencies of the U. S. federal government demonstrated a method of sharing knowledge between imagery analysts. The knowledge model that was created was an early demonstration of the IHMC's Concept Map-based knowledge modeling scheme. A small demonstration system was made that pertained to two areas of imagery analysis. This work involved the utilization, organization and representation of classified materials and information at the secret level, so little can be recounted here.

This work was performed with an early version of the CmapTools software. The software was set up to operate behind a firewall on one of the Intranets at one of the agency's facilities. Several issues were identified by this work, not the least important of which is the difficulty inherent in eliciting knowledge from individuals who are sworn to secrecy. Furthermore, compartmentalization issues were an impeding factor that introduced difficulties into the knowledge acquisition process. Nevertheless, the system demonstrated capabilities to elicit and share knowledge of a sort that is typically not extensively shared. A closely related topic to knowledge sharing is the use of captured knowledge for training and performance support, the topic of the next section.

4.2.3 Training and Performance Support

One potential use of Concept Maps in business and government that follows naturally from their use in educational settings is the use of Concept Maps and support materials in training. Concept Maps can be used as guides or advance organizers for material to be learned. Simple maps can serve as navigational guides to learning materials; more complex maps can provide an expert's view of the relationships among learning topics. Software can be used by trainees to navigate through training materials, can be modified by instructors, and so forth. Trainees and instructors can assess their own level of knowledge by building maps.

A system named El-Tech (Cañas et al., 1998; Coffey et al., 2003) was created to demonstrate a means of supporting the performance of in-fleet Naval electronics technicians. El-Tech was constructed in a joint research effort between the IHMC and the Chief of Naval Education and Training, Pensacola, FL. Figure 10 contains a graphic of the user interface to El-Tech. It illustrates typical components of the knowledge model, a Concept Map, a text passage and a video of the expert explaining a checkout procedure for the equipment. The left-most window illustrates an interactive question-and-answer session through which the system helps the technician diagnose a fault in the equipment.

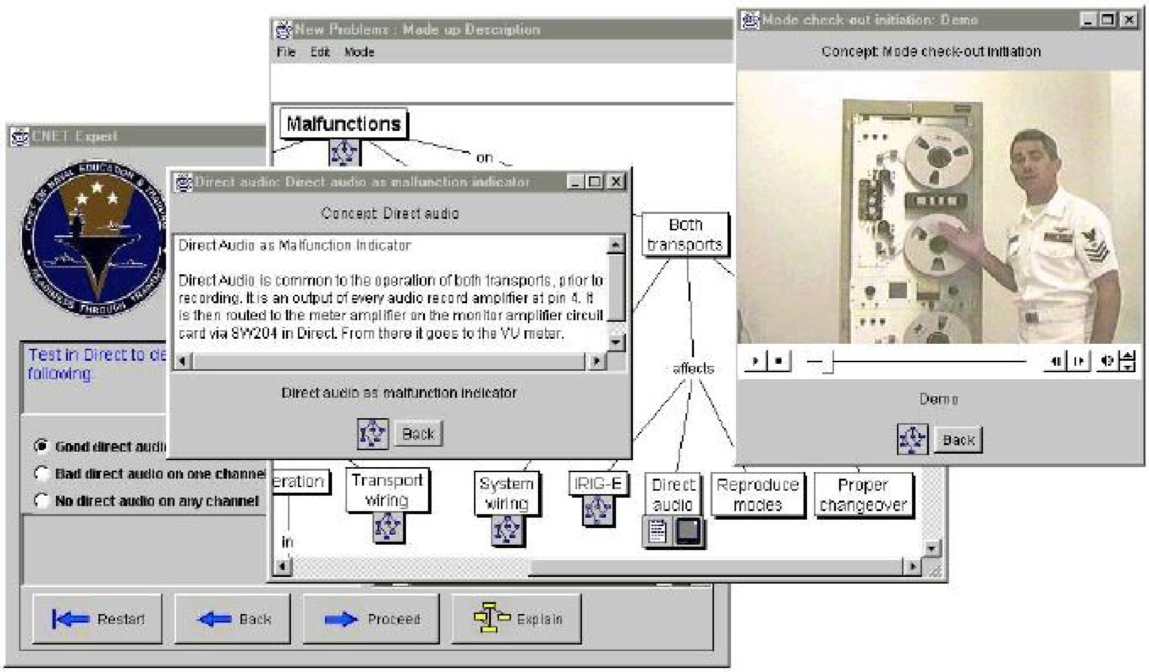

Figure 10. The Interface to El-Tech, a Performance Support System for Electronic Technicians.

4.2.4 Institutional Memory Preservation

The loss of institutional knowledge through retirements and other employee attrition is becoming a pervasive organizational concern as the “baby boom” generation ages and volatility continues to roil the workplace. (Allee, 1997; Brooking, 1999; Choo, 1998; Davenport & Prusak, 1998; O’Dell & Grayson, 1998; von Krogh, Ichijo, & Nonaka, 2000; Wenger, McDermott, & Snyder, 2002). A variety of strategies may be brought to bear on this problem, such as the implementation of exit interviews, attempts to create more comprehensive accounts akin to oral histories, and more systematic efforts to capture knowledge such as periodic archive updates by experts themselves or with facilitators. A few case-studies are presented next.

Smallenburg, Halman & van Mal (1996) described the creation and use of what they called “process knowledge maps” as a means of creating an historical record of how new products were developed in the concept phase of development. They provided an example of their approach from Colorproofing Systems, a company that develops and manufactures industrial printing systems. The idea they put forth is that the processes and the decisions made in the conceptualization phase can be archived and reused in subsequent projects. Figure 11 contains a depiction of their global process map. Their basic idea is to build exemplars of cases that relate to the various components of the process and to make these exemplars available to designers who are working on new projects.

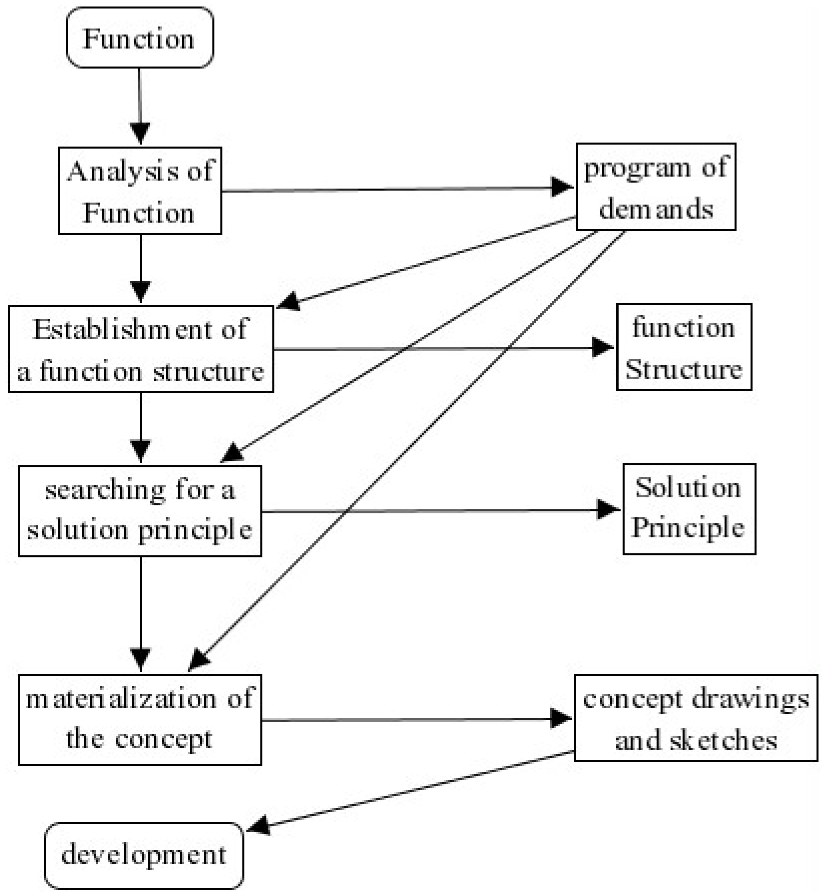

Figure 11. A Depiction of a Global Process Knowledge Map.

Gross, Hanes, & Ayres (2002) described the EPRI Strategic Human Performance Program, a project that seeks to ameliorate the problem of loss of undocumented knowledge due to departing or otherwise unavailable workers. Gross et al. were particularly concerned with the loss of knowledge that pertains to older systems that have been in place for many years and for which younger workers have had little or no training. This paper reports on an on-going, multi-year project that seeks to elicit and represent undocumented knowledge. Their knowledge elicitation strategies are based on Concept Mapping that is augmented with supplementary resources such as videos of the experts discussing matters of concern.

In collaboration with IHMC, EPRI has held two workshops to train personnel from the nuclear power industry to elicit and represent knowledge with the CmapTools software (see the section of research Concept Mapping tools for more information on CmapTools). To date, two workshops have been held with a total of 40 participants. The backgrounds of the trainees ranged from technical experts to human resources personnel. As a group, the participants clearly perceived a problem of loss of institutional knowledge, the need to identify strategies to retain knowledge that is being lost, and the value of Concept Mapping and knowledge modeling as potentially valuable parts of the solution. As of this writing, the use of Concept Mapping, knowledge modeling and CmapTools seem to be gaining increasing levels of use in this industry.

Coffey & Hoffman (2003) recently reported work that was performed at NASA Glenn Research Center. NASA has a problem similar to that of many large high-tech organizations—the loss of technical expertise over time. In an effort to address this issue, NASA funded a knowledge preservation project in which six senior engineers, all of whom were at or near retirement, were engaged in modeling experts' knowledge about launch vehicle systems integration. The sessions utilized the PreSERVe method of knowledge modeling, an iterative method of preparing for elicitation, scooping, eliciting, rendering and verifying (Coffey & Hoffman, 2003). Concept Maps were used as the structure in these efforts.

The basic focus question that defined the knowledge elicitation sessions was: "What are the major concerns of the engine and vehicle designers of the Centaur upper stage and RL-10 engine, and in what ways are these concerns complementary or contradictory?" This KE effort encompassed a total of 17 working days of contact with the experts, a very brief time commitment in terms of face-to-face contact with the experts themselves. However, significantly more time was required for the knowledge engineers and support personnel in preparation, review and transcription of notes, for the creation of the knowledge model, etc. Since the experts had worked for NASA or contractors for an average of more than 30 years, the result was a corpus of knowledge that included many of the highlights and lessons learned in 180 person/years of engineering work.

4.3 Other Examples from Industry

Most of the published literature from industry consists of preliminary studies, for instance, pilot studies that point to ways to solve knowledge management problems. Although this is generally the case, some studies can be found that present accounts of methods and tools that have effectively been put to the task in various ways and settings. The next sections contain summaries of work of both these types.

D'Amore, Konchady & Obrst (1999), described an initiative at MITRE Corporation to create domain ontologies using traditional knowledge elicitation methods. The authors called their approach ontological engineering. Ontological engineering consists of efforts to model data pertaining to a businesses' knowledge sources, and the conceptual relationships among those knowledge sources. An ontological account of such information comprises a searchable knowledge-based model of an organization, rendered in XML with semantic extensions. An ontological framework such as this can be used for additional knowledge capture and the creation of additional knowledge linkages in order to support knowledge management applications.

This method is being utilized in a pilot program that has the goal of identifying the entities, relationships and constraints within the operating center at MITRE. The approaches they are using strongly suggest the intent to utilize semantic modeling capabilities emergent in the Semantic Web initiatives.

Stanford (2001) construes knowledge mapping for knowledge management in the very broad sense of any non-textual, visual representation of knowledge that is used to elicit, codify, share, or expand knowledge. She described mapping both spatial and conceptual relationships as part of her notion of knowledge maps. She particularly honed in on the idea of "strategy maps," which are maps used for planning and implementation purposes.

She further divided the knowledge management function into areas and aspects. Areas are customers, collaborators, competitors, and the corporation – the internal organization. Aspects are people, the corporate culture, processes, resources, and tools. The approach she describes creates knowledge maps that map current state to desired state in the various areas and aspects of strategies the organization might adopt.

4.4 Other Applications in Military Settings

Applications of Concept Mapping in the military have substantial overlap with the applications described in the section on government and business. In order to extend that discussion, this section will present several examples of applications that are documented specifically for the military.

Golas et al. (1999) describe research and development of educational strategies for U.S. Naval Recruits. They were interested in the use of advance organizers as instructional aids. They carried out an application in fire fighter training. Students could select an advance organizer that took the form of text or a Concept Map. They hypothesized that field independent learners would prefer a graphic advance organizer, and that field dependent students would prefer textual presentations. They also had a control group that was given one hour of classroom instruction.

They reported that the advance organizer appeared to reduce stress – students reported greater "role clarity" and self-efficacy. In the discussion, Golas et al. suggested that use of Concept Maps and student selection of questions led to poorer performance on the test – students "wandered around" the material. They suggest this finding should be replicated before being given too much weight. They also concluded that the advance organizer helped classroom performance, whether it was provided via multimedia or in classroom setting.

The Task Force Excel workgroup has the responsibility to design a wide array of career paths for Navy personnel including professional development, personal development, and the certifications that are necessary at different stages of a sailor's career. In work on the professional development vector, the basic strategy is to carry out Job Task Analysis for each of the ratings in the U.S. Navy. JTA is a systematic method which uses small focus groups and a facilitator to reach consensus on a valid task list for a specific job. The method involves generating tasks, organizing tasks into coherent, related groups, and labeling grouped tasks. The first workshop of TFE JTA brought together 30 senior QMs, SMs and BMs to brainstorm jobs and tasks for the three ratings.

The CmapTools software was used in this effort. The software greatly facilitated the discussion of the responsibilities of the various ratings, and through the process, a career progression for the “Professional Mariner” was created. Another aspect of the workshop was the requirement to align the various certifications that were required along the career paths. All this was accomplished in two days. Additionally, Concept Maps were created regarding future challenges that job performance would hold for each of the ratings.

Bautsch et al. (1997) describe the problem of the increasing cognitive demands placed on pilots as high performance aircraft become more technologically complex. They report on work that sought to create models and theories that represent the domain complexity and associated operator activities as part of the creation of a human-centered design for the cockpit. This article describes the creation of a human-performance model of a fighter pilot developed through cognitive task analysis. The analysis was conducted based on the creation of Concept Maps and semi-structured interviews with fighter pilots. The Concept Maps were created through what the authors describe as “human-in-the-loop simulations of prototypical fighter aircraft tasks.” The model that resulted made explicit decision points, key concepts, information requirements, problems, and problem solutions encountered in the various mission scenarios.

5. Software Support Tools

5.1 Introduction: Tools, Types and Purposes

The applications or uses of Concept Mapping software tools have been discussed extensively in previous Sections of this report. The present section will be concerned with software tools that can be used to make diagrams that help in the visualization of knowledge or search results, or can be used to make Concept Maps or similar representations. Many knowledge graphing software tools have been developed. They can be grouped into several general categories including: Concept Mapping tools, Semantic Networking tools (Fisher 2000), Mind Mapping tools (Buzan & Buzan, 1996), decision making tools (also called group organizers), knowledge or memory management tools, and visualization or browsing tools. There is considerable overlap among these categories. For instance, tools from all of the categories support:

- the visual representation of knowledge as expressed in terms of concepts, ideas or "thoughts,"
- the associative creation of links and nodes, and
- the capability to organize related concepts for specific purposes.

The visual representation of concepts and ideas may act as a communication aid, or as an organizer of thought. At the simplest level, visual representations may be created manually, using paper and pencil, or Post-It™ notes. At the next level, standard diagramming tools such as Visio, SmartDraw, or even the drawing features in Microsoft Word can be used to construct Concept Maps. At the next level, more sophisticated graphing tools allow explicit representation of node and link structures. Finally, tools more specific to a particular graphing system (e.g., Mind Maps, Semantic Networks, Cognitive Maps, and Concept Maps), provide support for that particular graphing system, with specialized toolkits that support creation of a specific type of diagram.

In the remainder of this Section, we present a taxonomy of general diagramming and information visualization tools, including knowledge or memory management tools. A few examples are presented to illustrate the uses of these software tools. The main emphasis in this chapter is on software tools that were developed for the creation of Concept Maps or closely related representations. Accordingly, tools that support alternative mapping systems, such as Mind Mapping and Cognitive or Issue Mapping are discussed.

5.1.1. General Diagramming Tools

Many diagramming tools can be used to make Concept Maps although they were not specifically designed to do so. Diagramming software nearly always provides the capability to make boxes and links between boxes. Typically, some sort of tree diagram or flowchart is used as a template. Diagramming software does not necessarily promote or even allow the use of linking terms between boxes or nodes, though this capability may be achieved through work-arounds. Hence, there is no explicit prompt for the use of linking terms. Examples of this type of software include Visio and SmartDraw.

5.1.2. Visualization/Browsing Tools

The set of tools included in this category are not necessarily Concept Mapping tools in the sense that they do not always support the linking of concepts. The major goal of these tools is to assist in the representation of large amounts of information, in order to support navigation, search, or database management. Typically, information is represented as a network or web, similar to Fisher's Semantic Networks (1990), but without the linking phrases. Some of these tools allow the construction and linking of specific types of media, others provide clustering of concepts based on semantic analysis. These tools have been used to organize websites and to provide structure to intranets. A typical representation is a network of nodes, which may or may not be symmetrical or hierarchical in structure. In some cases, the network is dynamic and adjusts with user actions, or is searchable.

Some examples of visualization and browsing tools are *TouchGraph*, *StarTree*, *ThinkMap*, and *TheBrain*, These tools provide combinations of web-based, personal and business-oriented components. Additional tools to address the growing interest in semantic analysis and categorization for the organization of information are in development.

TouchGraph (http://www.touchgraph.com/) is an information visualization tool that works with Google™ to create a graph of search results. Applications have been produced at the National Science Foundation and PubMed using TouchGraph. Further information on the PubMed TouchGraph, which is designed to help browse the MedLine database, is available at http://www.pmbrowser.info/pubmed.htm An NSF TouchGraph may be viewed at http://www.touchgraph.com/nsf.jpg.

StarTree (http://www.inxight.com/map/) is a visual navigation aid that represents the structure of information in the form of a web. Its developers state that StarTree provides intuitive navigation, and easy, efficient organization of web content. StarTree enables the organization of many pages and documents into large hierarchical structures. In a study using a Hyperbolic Tree (an early version of *StarTree*), users were able to use the software to perform more efficient and thorough Web searches than with traditional browsers and search techniques. These results are reported at this website: (http://www.inxight.com/news/usability_study.html). Star Tree helps the user create a dynamic representation of a web site, with the ability to enlarge the portion of the tree that is currently being viewed, and to shrink other portions. Some applications of StarTree can be seen at http://www.inxight.com/products/core/star_tree/demos.php.

TheBrain Technology Corporation (http://www.thebrain.com/) has several products that assist users in managing data or knowledge, either at a personal level or at a business level. Relational information based on associative links is used to build networks of information in an automatic manner. TheBrain relies on searching and indexing capabilities that can access and navigate different types of resources. For personal use, Personal Brain 2.0 allows the user to organize web pages, documents, e-mails and so forth in a manner that makes them easy to find and retrieve. Web Brain provides a searchable and browsable index of web pages, based on a human-edited directory of the web. On the business level, TheBrain EKP provides the capability to integrate data from a number of network and Internet sources. It provides a way to visualize and navigate company resources. More information on TheBrain may be found at: http://www.webbrain.com/html/default_win.html.

ThinkMap (http://www.plumbdesign.com/products/thinkmap) is another tool that is designed for information management and visualization. Its developers promote its use to provide an interface for web resources. The developers have worked with several companies to create an interface that allows the user to explore topics of interest, and to see related information. Links represent different things in different applications, but are unlabelled and mostly association-based in nature.

These are a few examples of commercial software tools that are designed to support the visualization of information. The resulting visualizations are meant to be interesting, dynamic, and to promote navigation. However, in most cases, the interface does not provide the user with a sense of how information is connected. The sorts of relational information contained in the linking phrases in Concept Maps are not present in the links created using these software tools. Essentially these tools provide a graph without the meaningful relations that are expressed in Concept Maps.

5.1.3 Knowledge/Memory Management Tools

A number of software tools have been designed to assist in the management of institutional knowledge or memory, to provide capabilities such as database management, or to support semantic categorization, with some degree of automation for the formation of categories. These tools are based on a variety of theoretical and practical approaches, and have been used in both corporate and individual settings. There is some overlap among these tools in terms of their capabilities, and the tools often make use of a visualization element. Some have database management components or capabilities to provide semantic analysis.

Personal Memory Manager (PMM), which was developed in the Netherlands, is a tool that uses “concept engineering” to assist in the ordering of personal and organizational expertise (de Weijze, 1998, see also http://www.pmm.nl/philo/philo.htm). The PMM website refers to both Mind Mapping and Concept Mapping, and borrows heavily from Concept Mapping techniques. The graphs that are developed are similar to Jonassen’s Semantic Networks. Concepts have elements and notes, which can be shared. PMM also uses worksheets and database files, which can be used to specify interrelationships, and notes that can be included in the graph. PMM developers provide a list of sample applications that is available on the website. It is not made clear whether these examples are intended as demonstrations, or whether they describe actual customer applications.

A different kind of information management tool is *Mind Model*, (http://www.mindmodel.com) which supports the creation of personal or organizational relational databases that can be stored on individual computers, or shared over the Internet. Proponents claim that *Mind Model* can facilitate organizing, storing and retrieving isolated pieces of information or propositions, and can help users examine interrelationships among propositions. *Mind Model* is like a text-based (rather than graphically-based) Semantic Networking program.

5.2 Tools for Making Concept Maps and Closely Related types of Diagrams

We now consider software tools that are designed for the construction of Concept Maps or closely related representations. In most cases these tools are flexible enough to be used to build other types of diagrams, but typically are not as sophisticated and flexible as standard business diagramming tools for business charting. We will not review other types of tools such as those developed by Trochim (1989; 1989). Even though he calls his software "Concept mapping" tools, Trochim's software "The Concept System" does not support the creation of Concept Maps as we define them here.

5.2.1 Commercial Concept Mapping Tools

The tools considered in this section have a theoretical basis in Assimilation Theory proposed by Ausubel (1968) and Novak (1998; 2002). They provide the capability to create nodes and linking phrases in meaningful relationships or propositions, and may actively promote the use of Concept Mapping through prompts for concepts or linking terms. In some cases, accompanying tutorials or instructional materials provide assistance in the construction of good maps. Tools that fall within the category include:

1. *Inspiration* (http://www.inspiration.com/home.cfm)
   Inspiration uses a web as a basic graph structure, and repositions the initially entered concept in the middle of the screen. This tool does not enforce any particular graph structure, and the representation does not require linking phrases. The software allows the user to switch from graph to outline view and back.
2. *SMART Ideas* (Smart Technologies)
   This tool allows users to create multi-level Concept Maps to organize ideas, to link Concept Maps to files and Web sites, to switch between diagram and outline views, and to publish Concept Maps on the Web. More information may be found at (http://www.smarttech.com/products/smartideas/index.asp).
3. Hypersoft *Knowledge Manager*, http://www.concept-maps.com/default-eng.htm. This tool suite does not explicitly promote any type of representation, but leaves the organization of the graph as a user-defined property. *Knowledge Manager* does not require linking phrases in the representation.
4. Axon *Idea Processor*, http://web.singnet.com.sg/~axon2000/ is also a general-purpose mapping tool.
5. *LifeMap* (http://www.robertabrams.net/conceptmap/lifemaphome.html), is designed for free educational use. Group packages with support are available. *LifeMap* provides the capability to make Vee diagrams as described in Novak & Gowin (1984).

Many of these commercially-available software tools are flexible enough to allow construction of any sort of diagram. The creation of Concept Maps, as we describe them, is encouraged to differing degrees by these various packages. In the next subsection we describe Concept Mapping software tools that are still in development or that are used in research environments.

5.2.2 Research Concept Mapping Tools

This section presents descriptions of several of the more prominent tools that are still in the prototype phase. *Webster* is a software tool developed by IBM (Alpert and Gruenberg 2000) that allows the construction of Concept Maps. *Webster* is not currently a commercial tool, but may become one at some point. Currently, prototype versions are available for educators to test. *Webster* allows the incorporation of images and other media directly into the Concept Maps, as well as the attachment of resources. *Webster* also permits the development of submaps, easy transition of a map section to a submap, and conversion between map and outline format.

Researchers at the Knowledge Science Institute at Calgary had an early interest in the use of Concept Maps and multimedia (Gaines and Shaw 1995). They have developed a number of demonstration programs, such as *KSIMapper* and *CMap*. These programs are not available for purchase, and some of the capabilities have been integrated into *Smart Ideas* from Smart Technologies. The Calgary group is interested in the use of Concept Maps in multimedia, for education, collaboration, and for the capture of expert knowledge. The primary contributions to date appear to be the development of a C++ library that assists developers (CMap) and a demonstration program (KSIMapper). (Kremer and Gaines 1994; Gaines and Shaw 1995; Gaines and Shaw 1995; Gaines and Shaw 1995; Kremer and Gaines 1996).

The overriding goal of the IHMC *CmapTools* (Cañas, Hill, Carff & Suri, 2003) software kit is to enable users to collaborate during Concept Map construction and to easily share and publish the resulting knowledge models. The software is based on a client-server architecture (Cañas, Hill, Granados, Pérez & Pérez, 2003) that allows users to share and browse Concept Maps stored in CmapServers distributed throughout a network that covers the whole world. The servers support synchronous collaboration (two or more users constructing a Concept Map concurrently) and asynchronous collaboration through Concept Map sharing, the capability of adding annotations and discussion threads to Concept Maps, and through Knowledge Soups (Cañas et al., 2001).

CmapTools provide many capabilities for the creation of Concept Maps, including a highly intuitive, modeless editor and the ability to attach links to resources and other Concept Maps located anywhere on the network to concepts in Concept Maps (a patented feature). Thus, Concept Maps and accompanying resources that are associated with concepts in a map can be located on different machines running the server software. HTML versions of the Concept Maps are automatically generated for access from Web browser programs. *CmapTools* fosters the aggregation of Concept Maps for a knowledge domain and their associated resources into knowledge models (Cañas, Hill & Lott, 2003).

CmapTools has been extended to aid the user in the construction of Concept Maps. A search feature (Carvalho et al., 2001) allows the user to locate resources (including Concept Maps) and Web pages that are related to a Map, facilitating the addition of explanatory resources to the Map (all CmapServers in the network are automatically indexed making the search feature very fast). A WordNet server allows users to navigate through definitions, synonyms, antonyms, etc. for any word in a Concept Map (Cañas, Valerio, Lalinde-Pulido, Carvalho & Arguedas, 2003). And research is being done on "suggester" additions to the software that take advantage of the topology and semantics of Concept Maps to mine the Web and index servers to propose concepts (Cañas et al., 2002), propositions, resources, other Concept Maps (Leake et al., 2002), and topics for related Concept Maps (Leake at al., 2003), that will help the user improve his/her Concept Map. A new recorder feature allows the recording and step-by-step playback of the whole Concept Map construction process which will greatly facilitate the analysis of Concept Map building techniques and allow teachers and instructors to carefully re-examine the Map construction process of their students. Further information on the software tools is available at http://cmap.coginst.uwf.edu.

Luckie *Concept Connector* is a software suite currently in development at Michigan State University. This system allows students to build Concept Maps online, and to receive immediate feedback about their maps based on automatic scoring systems that are derived from scoring methods detailed in Novak & Gowin, (1984). The Concept Mapping system is based upon a pre-defined set of concepts and linking phrases. The system is currently being used for online homework assignments.

TPL-KATS (Team Performance Lab – Knowledge Assessment Tool Suite) includes modules for both Concept Mapping and card sorting (Hoeft, et al., 2002; 2003). The suite is designed to assist with the assessment of what the developers call "structural knowledge." The system computerizes the administration of tasks such as the logging of user actions and the scoring of completed maps. The system provides concepts, and requires that all concepts be used, and that all linking lines be labeled. The software includes an adminstrator mode in which task characteristics such as arrow types, whether or not participants can add concepts, and the maximum number of concepts, can be specified. The system can also be used to make fill-in maps, to attach multimedia and comments to maps, to prompt the user to specify the strength of a relationship, etc. Several different methods of scoring are provided. The system can produce output files based on mapping tasks and completed Concept Map characteristics that can be analyzed with standard statistics packages.

Chung, Baker & Cheak (2002) describe the most recent version of their knowledge mapping software, called the Knowledge Mapper Prototype system. Research with their system suggests that users take some time to become proficient. The authoring system allows instructors to define tasks for students by specifying concepts and linking terms, to designate an existing Concept Map as the "expert map" to be used as a scoring criterion, and to assign groups of users and associated group privileges. Their system is a relatively constrained Concept Mapping system, with predefined concepts and linking terms, although they describe some exploration of user-generated links.

5.3 A Semantic Networking Tool

One format of Semantic Networking has been described by Kathleen Fisher in the original versions of *SemNet* (Fisher, 2000). In counterpoint to the fact that many graphical software tools can be used to make Concept Maps even though they were not intended specifically to do so, many of the tools that have been developed to build Concept Maps can also be used to construct Semantic Networks as Fisher defines them. (e.g., *Inspiration*, *Knowledge Manager*, etc). Unlike Concept Maps, these Semantic Networks need not be hierarchical. Semantic Network software typically shows only a portion of the network at any time, specifically that which is most closely related to the current node of interest. *Semantica* (which is based on *SemNet*) is now a commercial tool with more information at http://www.semanticresearch.com/.

5.4 Mind Mapping Tools

These tools use the Mind Mapping methodology suggested by Buzan & Buzan (1996). These tools allow the construction of graphs that are built on "radiant associations" from a central point. Mind Maps are often very colorful, so that the best commercial software has sophisticated color and imaging options. There are many tools that have been developed to create Mind Maps. These tools are limited in the sense that they typically cannot produce any other type of graph structure, and do not allow for explicit linking terms within or across branches. Some of these tools have become fairly sophisticated in terms of linking to Internet resources, the addition of notes and support for collaborative use. The most widely used and developed versions include:

1. *Mind Manager* from MindJet http://www.mindjet.com/index.shtml,
2. *Visual Mind* http://www.visual-mind.com/
3. *VisiMap* by CoCo Systems http://www.coco.co.uk./.
   http://www.coco.co.uk./prodvm.html
4. *Mind Mapper* from SimTech USA http://www.mindmapper.com/
5. Concept Draw has a Mind Mapping product, as well as general drawing and diagramming products that integrate with *Visio*. More information may be found at http://www.conceptdraw.com/en/products/CDPMindMap/.

5.5 Decision Making Tools/Group Organizers

A number of software tools support diagramming for group decision-making. These tools typically have these basic elements:

- they allow for the representation of a large number of concepts/ideas,
- they are described as idea mapping tools,
- the "mappings" are always based on causal relations,
- they use short phrases to express ideas, including active verbs,
- they allow for single or bi-polar relationships which are usually directional, between concepts or ideas, and
- they encourage hierarchical structuring.

A number of graphing tools and systems have been developed for use in decision-making situations. These tools may support a structured argument or evidence diagramming approach, such as that used in Belvedere (Paolucci, Suthers et al., 1995; Suthers & Hundhausen, 2001). Alternatively, a number of less structured graphing systems may be used, such as Causal Cognitive Mapping, or Issue-based Mapping.

Cognitive Mapping and Issue-based Mapping are designed to help people solve difficult (so-called "wicked") problems, to which there is no simple solution. They begin at a common point, which is often the brainstorming and diagramming of ideas that are related to the problem. Cognitive Mapping (Eden, 1988) was developed in the context of strategic management, and is said to be based on Kelly's Personal Construct theory (Kelly, 1955, cf. Ackerman & Eden, 2001). Cognitive Mapping is intended to be a general tool for the structuring of ideas. Connections among nodes are often causal. Cognitive Mapping can be used to build very large networks.

Decision Explorer (from http://www.banxia.com/demain.html) is software that is designed for the construction of Cognitive Maps, although other types of diagrams can be built, such as Concept Maps or Mind Maps. *Decision Explore*r can be used by an individual or by a group. *Decision Explorer* also includes capabilities for graph analysis, which are based on the structure and interconnections within each diagram.

Questmap (from http://www.softbicycle.com/) is another type of diagramming software that is based on idea mapping. It extends Issue Based Information Systems (IBIS) to include graphical representation and linking of nodes using a Visual Issue Mapping System (VIMS). Nodes contain questions, ideas or information, and are linked. *Questmap* is specifically designed to address group decision-making and problem solving. *Questmap* is described as a Group Decision Support System (GDSS). More information may be found at http://www.gdss.com/omq/aboutQM.htm.

Concept Star (http://www.sorach.com/) is another group diagramming tool to aid in decision making. In the Concept Star approach, the process of creating a diagram involves generating ideas, prioritizing and considering relationships among them. The focus in Concept Star diagrams is on ideas rather than concepts. Ideas are associated with counts or votes, which indicate relative support for the idea. Links between ideas are not explicitly labeled, although newer versions allow users to select from a list of link labels. *Concept Star* uses "interpretative structural modeling" (Warfield, 1973, as cited on web page), which is a computer assisted learning process to aid in the development of a diagram of relationships in a complex domain. Concept Star appears to support use of many different types of diagrams and tables.

Belvedere, (http://lilt.ics.hawaii.edu/lilt/software/belvedere/index.html) can be used to construct graphical representations of ideas. The software has been used in middle-school and high-school to help students learn critical inquiry skills that they can apply in everyday life as well as in science. The software was originally developed by Dan Suthers at the Learning and Resource Development Center at the University of Pittsburgh, and is undergoing current development at the Laboratory for Interactive Learning Teachnologies at the University of Hawaii. The fourth version of *Belvedere* is now available. The latest version supports multiple representational views (tables and hierarchies as well as graphs) on evidence models, Concept Mapping and Causal Modelling. *Belvedere* has been used in educational settings to support student reasoning and collaboration (e.g., Toth, Suthers et al., 2002).

The Project Integration and Visualization Tool (*PIVit*) allows for visual depiction of project plans represented as graphs and subgraphs. *PIViT* is a product of the Project-Based Science Group at the University of Michigan, and is supported in part by grants from the National Science Foundation and an Eisenhower Grant from the Michigan State Department of Education. This tool can be used to build Concept Maps, however the examples that are presented do not have linking phrases. The website http://www.umich.edu/~pbsgroup/PIViT.html provides a description of *PIViT*, and information on its development and uses. The main use seems to be to create diagrams of ideas and sequences of activities related to a project. More information on *PIVit* may be found at the following website: http://www.umich.edu/~pbsgroup/ProjDesign.html.

6. Summary and Conclusions

The mandate of this work was to provide a summary of the literature on Concept Mapping and similar representations as they could be used for education and job performance. It has been 26 years since Dr. Joseph Novak proposed the idea of using Concept Maps to represent and externalize what a student knows about a subject. In that time, a huge volume of literature has been created on that and other uses of Concept Maps.

In this report, we present a discussion of the defining characteristics of concept maps: their grounding in Ausubel's Assimilation theory of learning, their semantic and syntactical (structural) organization, the nature of concepts that comprise the nodes in a Concept Map, and the unconstrained nature of linking phrases. The motivation for the creation of concept maps came from Novak's wish to follow and understand changes in children's knowledge of science. Novak was aware of Ausubel's very important distinction between *rote learning* and *meaningful learning*, and he hoped to encourage meaningful learning in children through the use of concept maps. Novak suggests that Concept Mapping is powerful for the facilitation of meaningful learning because it serves as a way to help organize and structure knowledge.

This report contrasts Concept Maps with other types of mapping systems, such as Knowledge Maps, Cognitive Maps, and Mind Maps. Knowledge Maps are characterized by narrowly focused concepts like those in Concept Maps, but Knowledge Maps feature pre-specified sets of linking phrases. Semantic Networks as described by Fisher, have a topic node centrally located and other concepts that pertain to the basic concept radiating out around the main concept. They are reminiscent of Concept Maps without hierarchical structure or cross-links. Cognitive Maps feature nodes that are called ideas, which are typically expressed as entire phrases. They contain no relationship indicators on the linking lines. The Concept Map representation subsumes all the other types of graphical representations of knowledge.

We describe a standard procedure for Concept Map construction. The procedure starts with the definition of the topic or focus question. It is critically important to take the time to do this since a Concept Map can lack focus, and the most typical reason why a map might end up in such a state is because of the lack of a clear idea of what the mapper is trying to represent. The goal of the concept mapping session has major impact on the nature of the focus question. If, for instance, the purpose of the Concept Map is to determine what a student knows, then the teacher must have a question clearly in mind. If, on the other hand, the purpose is to elicit knowledge from an expert, the focus question might be more difficult to formulate initially, and may undergo revision as the session goes forward.

In the standard Concept Mapping process, the basic steps after identification of the focus question are identifying and listing the most important or "general" concepts that are associated with the topic, ordering the concepts from top to bottom in the mapping field, and adding and labeling linking phrases. Once the preliminary Concept

Map has been built, cross-links are identified and added, and a review of the map for completeness and correctness is performed.

Several alternative approaches to Concept Map construction have also described. Some of these mapping variations are based on the use of software tools, the pre-specification of concepts and/or link labels, and individual versus collaborative mapping sessions. Individually produced Concept Maps and those produced by groups can be made with the assistance of human or software-based facilitation. Many facilitation procedures are possible in Concept Map construction, ranging from support provided to novices who are learning to create Concept Maps, to support of a group of experts who work in conjunction with a facilitator or knowledge engineer. Several types of support are described that can be built into Concept Mapping software to provide ongoing assessment and facilitation of the mapping process.

In facilitated mapping sessions, the skill of the facilitator has a significant bearing on the quality of the result. If a session involves brainstorming, it is imperative that the facilitator has good keyboarding skills in addition to an understanding of how to facilitate the building of concept maps. It is also quite clear that group dynamics play a significant role in the quality of a concept mapping session. It can be less than optimal, or even counter-productive for large, highly contentious groups of people to attempt to create collaborative concept maps.

This report reviews a large body of literature on the uses of Concept Maps for education. These studies on learning with Concept Maps point to some informative results. First, when Concept Mapping is used in a course of instruction, it is better that it be an integral, on-going feature of the learning process, not just some isolated “add-on” at the beginning or end. In this regard, Concept Mapping appears to be particularly beneficial when it is used in an on-going way to reinforce other educational experiences.

When Concept Mapping is used in an ongoing fashion, learners experience an educational event and then use Concept Maps in a reflective way to enhance the learning from the event. There is also indication that learning effects are enhanced when, in the course of Concept Mapping, learners adopt an active, deep and questioning approach to the subject matter. Certainly, active, self-engaging, transformational interactions with learning materials of a variety of types facilitate learning. This kind of interaction can be engendered by a teacher/facilitator who challenges the learner to explain, justify, and formulate questions in the course of building a Concept Map.

When Concept Mapping is compared with other sorts of activities such as outlining or defining concepts that also can induce the learner to take a thoughtful, systematic approach to engaging subject matter, the positive benefit often diminishes. However, even in these situations, it appears that Concept Mapping is especially good, in comparison to other interventions, for the learning of *relationships* among concepts. Understanding concepts and their underlying relationships is widely held to be necessary to the acquisition of flexible, generalizable knowledge.

We described at some length the uses of Concept Maps and similar representations in business and government. Knowledge in an organization can be characterized as falling on a continuum from a general, global level of a business or governmental entity, to valuable but highly focused knowledge within a particular area of the organization. Useful knowledge can also be characterized as retrospective, concerned with what individuals within the organization knew and did, or prospective, trying to anticipate or conceive of future directions. Knowledge of either of these sorts might be leveraged and shared. Finally, knowledge can be personalized if it resides in people, or it can be codified through capture and representation in a form that can be shared. We described uses of Concept Maps and similar representations for the capture and dissemination of knowledge that falls along all these dimensions.

We presented a number of case studies from business and government that have exploited a variety of graphical representations, many of which are Concept Map-like, to serve a variety of purposes. Clearly, it is important to choose "the right representation for the job," but for many jobs, Concept Maps quite clearly have a role to play in the form of a simple, intuitive knowledge representation scheme.

Many of the studies from business and government are preliminary. The recognition that the aggregate knowledge of an organization is a valuable asset that must be protected, maintained and augmented, has created a rapidly escalating interest in knowledge elicitation and representation, facilitation of brainstorming techniques through concise, graphical representations of knowledge, etc. Much of the reported work is preliminary or sketchy because many organizations are just now attempting to ramp up large-scale capabilities to preserve, generate and share knowledge. The quality of the work that is reported is variable.

One of the big issues for organizations that have a concern for knowledge management (which is to say, any that want to remain viable), is how to capture and leverage day-to-day, mission critical knowledge. Even the challenge of separating what is critical and narrowly held from that which is widely held or easily attained, is a difficult problem. It is improbable that a panacea for this problem will be found. However, the capture of conceptual knowledge in a representation such as a concept map, which is extraordinarily easy to create, certainly provides a partial answer.

Since it is daunting to consider tasking already over-worked employees with additional work pertaining to knowledge capture, it is critical to adopt minimally intrusive means of doing this. Concept maps were originally conceived for, and have been made by children. They are very simple for adults to make after only a relatively small amount of training. Furthermore, clear successes such as those described by McNeese et al., suggest that uses of graphical tools such as concept maps have an important part to play in knowledge generation, capture and representation.

We present a range of studies in which Concept Mapping has been used in military settings. Cases were presented in which Concept Mapping was used for brainstorming, capture of design details, performance support, and other uses. We found substantial overlap between the uses that have been identified in the civilian sector: teaching and learning, brainstorming, expertise capture for knowledge-based systems, etc., and those in the military. It is quite clear that group elicitation and brainstorming with Concept Maps could be quite useful for mission planning and other strategic and tactical planning.

The literature suggests that a variety of representation schemes are needed to capture the full gamut from conceptual knowledge to procedural knowledge. As an example, complex process rules might be captured in a spreadsheet that can be used to conduct sophisticated "what if" calculations. The most suitable final representation very well might be a spreadsheet. However, the assumption of the existence of such a representation begs the question of the means through which the knowledge behind the rules is captured. Concept Maps have proven to be as efficient as any of the many other generally known knowledge elicitation schemes for making knowledge held by experts explicit.

The literature supports the claim that diagramming in general, ranging from circularly-organized concept nodes connected by unlabeled lines, to Concept Maps, can be used effectively to elicit expert knowledge. Such representations of "mental models" or the domain knowledge of individuals span the range from novice to expert. Even studies employing (or eliciting) diagrams that are only marginally Concept Map-like (diagrams that manifest only some of the defining morphological/semantic properties of Concept Maps) conclude that these sorts of diagrams show some utility for knowledge elicitation and representation.

Software systems that have been developed using Concept Mapping, and software systems that utilize Concept Maps (i.e., as interfaces) have generally been based on a satisficing criterion. Evidence of usefulness, usability, performance enhancement, or organizational effectiveness is not provided conclusively. However, the identified applications of Concept Maps have a clear track record of successful demonstrations in a range of domains. Further research is needed to demonstrate usefulness, usability, and net performance gain using Concept Map-based knowledge elicitation or Concept Map-enhanced intelligent systems.

We have presented a survey of a number of graphical software packages and tool suites that can be used as learning devices, for knowledge elicitation and representation, for brainstorming, etc. We have described various commercial tools and those that are still being developed in research settings. Two basic distinctions may be identified from this review. The first distinction is between general drawing tools that can be used to create a variety of diagram types and more special-purpose tools. While the general tools offer flexibility, they typically do not provide guidance in the effective construction of any given type of diagram. The special purpose tools give more targeted help on the types of diagrams they can be used to create. All the tools surveyed have their own unique characteristics with regard to how general or special-purpose they are, the sorts of diagrams they support, and the level of help they provide to the user.

The second distinction involves the quality of the representations themselves. A well-conceived software package that is used to create representations that are not particularly rich, or that do not fit the intended purpose of the user, may not be very useful. On the other hand, a powerful tool that is difficult to use or only supports a limited range of not particularly rich representations is not ideal either.

In the final analysis, the engineering dictum to “use the right tool for the job” applies in the selection of a representation of the sort that we have considered here, and a tool to realize the representation. By any measure, software packages designed explicitly for the construction of concept maps, which can be used for the creation of everything from preliminary student Concept Maps to very large-scale, Concept Map-based knowledge models, have very broad utility. Programs like CmapTools further enhance the concept mapping experience by providing a network architecture over which collaboration and sharing can easily take place.

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Appendix A

Other Mapping Systems

Introduction

The primary concern in this appendix is to describe graphing systems that are similar to Concept Maps, but are distinguished from them. The major criterion for inclusion of a graphing system in this discussion is a node-link structure and a mechanism to express relationships between concepts. Thus, our discussion includes Knowledge Maps (that have two somewhat different formulations: one from the Texas Christian University group (Bahr & Dansereau, 2001; Chmeilewski & Dansereau, 1998; Hall, Dansereau & Skaggs, 1992) and another by the CRESST group (Herl et. al., 1999; O'Neil, 1999; Osmundson, Chung, Herl & Klein, 1999)), Semantic Networks (having different formulations by Jonassen (2000) and by Fisher (1990; 2000)), Cognitive Maps (Ackerman & Eden, 2001; Eden & Ackerman, 2001), and Mind Maps (Buzan & Buzan, 1996). Other graphing systems that are called "Concept Maps" (e.g., Trochim, 1989a; 1989b) can be very different in both structure and procedure, (e.g., by relying on brainstorming and a statistical procedure to identify basic ideas and presenting them in a dimensional space, without specific concepts and links), and are not included.

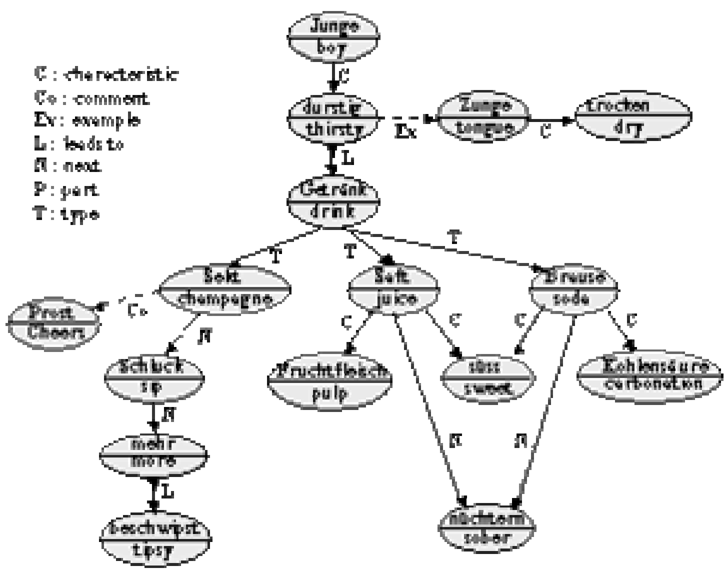

Figure 12. A Knowledge Map from TCU.

Knowledge Maps (TCU). Knowledge Maps, as developed by the research group at Texas Christian University, began as a study strategy called networking (Holley & Dansereau, 1984). Researchers at TCU have tested the use of Knowledge Maps as an alternative to text presentations of numerous topics (Bahr & Dansereau, 2001; Dees, Dansereau, Peel & Knight, 1992; Hall et al. 1992); Lambiotte, Skaggs, & Dansereau, 1993; Rewey, Dansereau, Dees & Skaggs, 1992; Rewey, Dansereau, Skaggs & Hall, 1989 , and have used them in counseling situations (Dansereau, Joe & Simpson, 1993; Dansereau, Dees, Greener & Simpson, 1995; Dees et al., 1992; Pitre, Dansereau, Joe & Simpson, 1997). . Figure 6 presents an example of a knowledge map.

Knowledge Maps differ from Concept Maps in a number of ways. The most obvious difference is the way that linking phrases are used. In Knowledge Maps, link labels are presented in abbreviated format, and are limited to a relatively small set such as *is_a, part_of*, or *example*. As such, Knowledge Maps as Dansereau et al. define them are essentially Conceptual Graphs. Depending on the setting and format, the restriction on linking terms also affects what appears in the nodes. To Dansereau et al., nodes represent knowledge rather than concepts, and can be words, sentences or paragraphs. TCU researchers have explored the effects of map format (Wiegmann et al., 1992) but typically do not restrict maps to a hierarchical format. O'Donnell et al. (2002) suggests that Knowledge Maps may represent a number of different knowledge prototypes, including hierarchical and other representations.

Knowledge Maps (CRESST Center for Research on Evaluation, Standards, and Student Testing). The CRESST group calls their representation scheme Knowledge Maps. Researchers at CRESST (Herl et. al., 1999; O'Neil & Klein, 1997; O'Neil, 1999; Osmundson et. al., 1999; Ruiz-Primo, Schultz, Li & Shavelson, 2001; Ruiz-Primo & Shavelson, 1996; Shavelson, Lang & Lewin, 1994) have been actively exploring uses of Concept Map-like representations, with the goal of developing computerized systems for graph construction and assessment. Much of the early research by this group focused on the differences in graph construction methods, and the implications of different methods on the assessment of completed graphs (e.g., the variability in scores, the relationship of map scores to other knowledge assessment measures, etc.). The primary concern of CRESST is to assess the viability of Knowledge Mapping as an educational evaluation tool.

Following Novak & Gowin (1984), the CRESST group asserts that their Knowledge Maps are constructed from concepts and meaningful linking terms. To this extent they are like Concept Maps. However, in Knowledge Mapping the concepts and linking phrases are pre-specified, and developed on the basis of expert knowledge from teachers or domain experts. When students construct Knowledge Maps, they start from concept lists and linking phrase lists provided by the software. The use of pre-specified concepts and linking phrases simplifies the scoring of maps, which are scored on the basis of a match to graphs constructed by experts. Recent research by CRESST is addressing the use of user-specified linking terms (Chung, Baker & Cheak, 2002; Cheak, Chung, Baker, Phan & de Vries, 2002) .

The structure of Knowledge Maps is totally unconstrained. The CRESST group has suggested that although hierarchical representation is appropriate in many domains, it may not be useful in others, and that the restriction of representation to hierarchical is not necessary (Ruiz-Primo, Shavelson & Shultz, 1997). Knowledge Maps are often complex networks of concepts, with a greater emphasis on concepts and their interrelations than on graph morphology.

Semantic Networks (Fisher). Semantic Networks, as defined in psychology, express the semantic similarity or associative frequency of words or concepts. However, as used by Fisher (1990; 2000), Semantic Networks are networks of nodes and links that are richly interconnected, that have labeled links between nodes, but are not strictly hierarchical in nature. Thus, they are more like Concept Maps than Semantic Networks, as these are regarded in mainstream psychology and computer science. Like Concept Maps, Semantic Networks are based on the use of concepts and meaningful, unconstrained linking labels, forming basic instances or propositions. Fisher suggests that Semantic Networks can be viewed as n-dimensional rather than 2-dimensional. Semantic Networks can become very large, and can contain hundreds of interrelated concepts. Because of their size, the user may only be able to view part of the network at any point in time, and this view is structured as a web, showing concepts directly related to the central concept. Figure 13 contains a graphic of the top level of a Semantic Network. Many of the topics, such as "Classical Music," can be expanded to reveal a Semantic Network specifically pertaining to them.

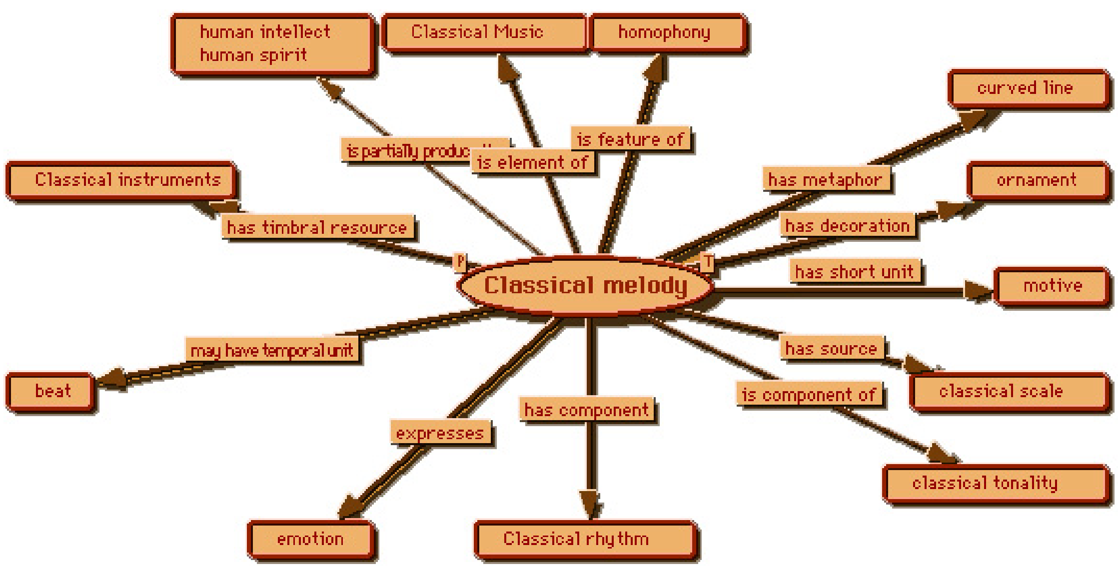

Figure 13. An Example of Fisher's style of Semantic Network.

Semantic Networks (Jonassen). Jonassen (2000) does not make any clear distinction between Concept Maps, Semantic Networks, and Cognitive Maps. He uses the terms interchangeably, and refers to "hierarchical Concept Maps" as a special type of Concept

Map, or a special type of Semantic Network. Lack of clarity in his use of terms makes Jonassen's work problematic. The graphs included in Jonassen's Semantic Networks (2000) maintain the same definition and uses of linking phrases and concepts as we define them and as they are used in Fisher's Semantic Networks, but differ from both these representations by lacking a semi-hierarchical structure.

Cognitive Maps (Eden). Cognitive Maps or causal maps, as defined by Ackerman & Eden (Ackerman & Eden, 2001; Eden, 1988, 1992; Eden & Ackerman, 2001) are large interconnected networks of ideas represented as nodes. Ideas differ from concepts in that they are typically sentences or paragraphs. Cognitive maps are implemented in Banxia's Decision Explorer. Cognitive Maps (Eden, 1988) are based on personal construct theory, according to which ideas (or nodes) are typically bipolar in nature, although other types of nodes are possible. Ideas in Cognitive Maps are interconnected by directional links, which are unlabeled. The implicit label for a link is causal or "leads to." Cognitive Maps are not hierarchical and typically take the form of a large complex network containing hundreds of ideas, which may have more than one focal point. Cognitive Maps were created to help people frame issues or work on problems, and are similar to IBIS and VIMS (Conklin 2002a; 2002b; Conklin et. al., 2002). These mapping systems have been used in group decision-making and business. Figure 14 presents a Cognitive Map. The Banxia Decision Explorer website provides a list of references about the use of Cognitive Maps in management (http://www.banxia.com/dexplore/debiblio.html).

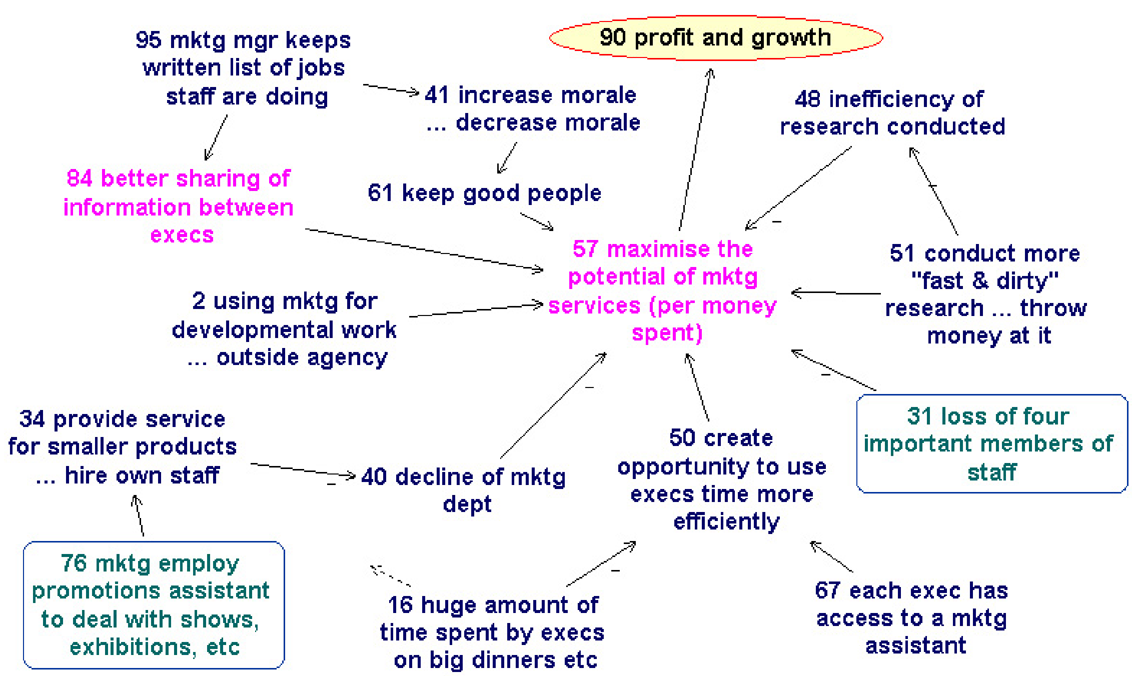

Figure 14. A Cognitive Map made with Decision Explorer.

Mind Maps (Buzan). Mind Maps are web-like graphs, in which ideas radiate out from a central topic in a manner said to be like the association between thoughts (Buzan & Buzan, 1996). There may be hierarchical relations and levels of branching, however the linking process is said to be primarily based upon association. Hence, the links between nodes ("thoughts" and "topics") are unlabeled, and typically represent unspecified connections among ideas. Buzan & Buzan (1996) has suggested that the use of images and color in Mind Maps may assist in adding meaning to the graphs, and in adding organization of related ideas in the maps. Buzan also suggests that Mind Mapping is a useful brainstorming technique. However, the lack of labeled links limits the usefulness of these graphs by different groups, or even by the same group at a later time. Informationally, the Mind Map structure offers little more than a circularly-arranged list of related or grouped ideas. Figure 15 presents an example of a Mind Map.

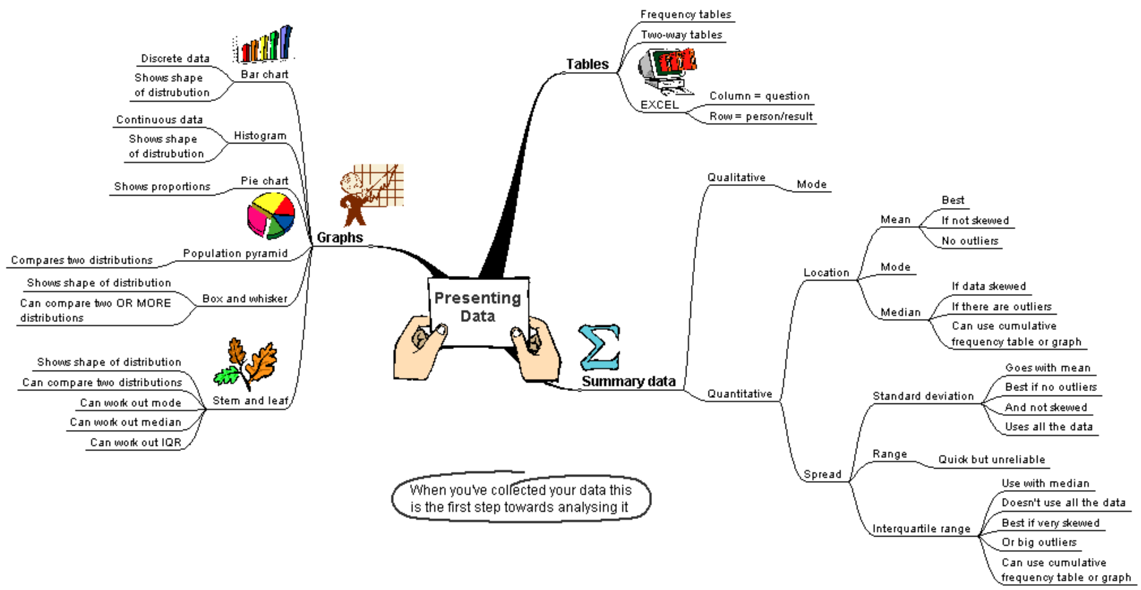

Figure 15. A Mind Map.

Appendix B

Evidence of Effectiveness of Concept Mapping for Education

Introduction

Concept Mapping had its roots in education, and education and learning probably still constitute the bulk of its use. Hence, the purpose of this chapter is to review a number of studies of the effectiveness of Concept Mapping as a learning tool. The issue is not *whether or not* Concept Mapping enhances learning. Like any other tool, the effectiveness of Concept Mapping depends on how it is used and the conditions in which it is used. There is no doubt that Concept Mapping *can* enhance learning. An earlier review of the educational effectiveness of Concept Mapping (Horton et al., 1993) concluded that Concept Mapping can have educational benefits that range from what can only be described as huge, all the way to having negative effects (i.e., when some alternative instructional intervention produced learning effects greater than Concept Mapping), although the great majority of the studies reviewed showed differing degrees of positive effect for Concept Mapping. The more useful question involves determining the ways and contexts of use that most enhance the contribution to learning that Concept Mapping can provide. That is the aim of this chapter. The studies examined in this chapter overlap some with those of Horton, but also include many newer ones.

In choosing the studies to include in this chapter, we have tried to focus on the ones that were the best designed. What does this mean? First, in a well-designed study, there is some kind of randomization in the assignment of learners to learning conditions. This helps to control for pre-existing differences in groups before any new learning occurs. There should also be some reasonable control for the experimental learning task, either the "normal" course of study without Concept Mapping, or one with some other alternative to Concept Mapping, such as outlining. Some care should be exercised to equate the time that learners in different conditions spend on learning. Clearly, if one group spends longer studying than another, this can cloud any effects of the particular learning treatment. In addition, there should be some reasonable description of how Concept Mapping is actually used in the instructional intervention. Finally, there should be a good description of what kind of test was used to assess learning, since different kinds of instructional methods can contribute differentially to different kinds of learning, e.g., simple recall of information or higher order reasoning such as inference. With these guides in mind, we now review studies that, at least for the most part, meet our criteria

Studies with Random Assignment of Learners to Conditions

Esiobu & Soyibo (1995)

The purpose of a study by Esiobu & Soyibo (1995) was to test effects of Concept Mapping and Vee diagramming in different forms of instruction, e.g., small group vs. large group, cooperative, vs. competitive. The study took place in Nigeria and involved secondary school students (said to be equivalent to tenth grade high school students in the United States). The subject matter was ecology and genetics.

The design for the study was a Pretest-Posttest combining Concept Mapping vs. Control; Learning Condition (small group versus lecture); Academic Ability (low-medium-high); and Gender. This was a large-scale study with 406 students in the treatment groups and 402 in the controls. Students were randomly assigned to their conditions. Achievement was measured by three specially developed tests (all 40 item multiple choice): a biology achievement test, an ecology achievement test and a genetics achievement test. The tests were reviewed by experts for their appropriateness for the classes. No information was given on the extent to which the test measured higher order thinking.

Students in the control groups did no Concept Mapping. In the treatment groups, Concept Mapping and Vee-diagramming were conducted in every lesson, either individually or in small groups, depending on condition. The Concept Maps were graded by the teachers. It appears that the Concept Mapping was used as an integrating device for lessons, i.e., to capture the essence of a lecture or demonstration. Students would experience some instruction first, then they would use Concept Mapping and Vee diagramming to help put it all together. Hence, Concept Mapping and Vee diagramming were a daily, integral part of the instruction in the treatment conditions.

The results were that students in the treatment conditions greatly outscored those in the controls in all learning conditions. A number of effect sizes[1] were on the order of 2.0. There appear to have been some general benefits of cooperation as well. This is one of the strongest demonstrations of the educational effectiveness of Concept Mapping to be found. Unfortunately, as is the case in many pertinent studies, the effects of Concept Mapping are confounded with those of Vee-diagramming.

Schmid & Telaro (1990)

Schmid & Telaro (1990) sought to test the effectiveness of Concept Mapping on high school biology achievement and to assess this by student academic ability level. The study was conducted in Montreal, Canada and involved students at levels "4 and 5" of the Canadian system. The subject matter was a unit of a biology course on the nervous system. The experimental design combined Treatment and Control crossed with three levels of Academic Ability (high, medium, and low). Students were randomly assigned to classes and classes were randomly assigned to treatments. This was a rather small-scale study, with numbers of students in each cell ranging from only four to eight.

The Stanford Diagnostic Reading test was used to divide the students into the three levels of academic ability. The tests used for measuring biology achievement were

[1] "Effect Size" is the difference in mean scores of two groups being compared on some score, divided by the standard deviation. It gives a measure of the magnitude of the difference in terms of number of standard deviations. Hence, an Effect Size of .5 means that the mean of one group is one-half a standard deviation larger than the other. An Effect Size of 1.0 means that the mean of one group is one standard deviation larger than the other, 2.0, two standard deviations, and so forth. Which magnitudes are "small" or "large" is somewhat in the eye of the beholder. However, an Effect Size of 2.0 is most surely very large (cf. Bloom, 1984). This indicates that there is virtually *no overlap* in the scores of the two groups; the scores of one group totally eclipse those of the other. Different ways of calculating ES are determined by how the standard deviation used in the calculation of the Effect Size is computed. In this chapter, the standard deviation used has been the standard deviation of the control group, an acceptable method (e.g., Cohen, 1988).

all composed of a combination of items taken from state examinations, textbook questions, and teacher-made questions. There was a 20 item multiple choice test used as a pretest, and a midterm test with 25 multiple choice and 15 matching items. In addition to 20 multiple choice items, the posttest contained a number of special concept-linking and explanation items that the authors speculated would be particularly suitable for addressing the effects of Concept Mapping.

The two groups were taught by the same teacher. The teaching was lecture based, with some laboratory work. The only difference between the treatment and control conditions was that students in the treatment group made Concept Maps after each instructional presentation. Concept Mapping was an integral part of the course for those students. As in Esiobu & Soyibo (1995), the Concept Mapping seems to have been used as an integrating and consolidating experience after some body of traditional educational presentation. The instructor and the students discussed their Concept Maps and the instructor answered questions and gave feedback. The instructor graded the Concept Maps at night and handed them back to students the next day.

The treatment group learned Concept Mapping by doing it in the classroom (at designated points) and getting guidance and feedback. There were no separate and disconnected learning sessions for the Concept Mapping work. Although the Concept Mapping group generally surpassed the control on the criterial tests, the only statistically significant result of particular interest is that in the lowest ability groups the Concept Mappers greatly outperformed the controls, but only on the special part of the posttest that was supposed to measure relationships among concepts etc., the "mapping-friendly" section of the exam -the effect size on this part was approximately 1.4.

The number of students in the statistical comparisons was quite small and test duration was short. These factors could account for the fact that the results, while generally favoring the Concept Mapping groups, showed only one statistically significant effect. The results did indicate that the helpfulness of Concept Mapping increased as groups went from high to medium to low ability. The authors speculate that Concept Mapping helps low ability students because it requires them to take an organized and deliberative approach to learning, which higher ability students likely do anyway.

Bascones & Novak (1985)

The goal of a study by Bascones & Novak (1985) was to test the effect of Concept Mapping on students' problem solving in physics. The teaching process used in this study was based on Ausubel's (1968) theory of meaningful learning. The study was conducted in Venezuelan secondary schools, with students who were about 14+ years of age. The course was a required physics course taught throughout Venezuela. The design involved two groups, created in the flowing manner. Seventy-six students were chosen randomly from an available pool of 400. These students were then stratified for three levels of academic ability based on their scores from the Raven's Test of Progressive Matrices. They were then further divided into two groups of 38 each, treatment and control, such that the groups had similar intellectual levels. It is not clear what degree of randomization was actually involved in this latter stage of the process.

A set of eight multi-step problem solving tests (each test was one problem) was created by the researchers and administered one at a time after each “unit’ throughout the course of instruction. (No actual examples of the problems are given.) These problems, with a maximum score on each of 15 points, assessed the students’ ability to analyze, solve, and defend their approach to the problem and their answer. The four basic steps (with substeps within each) in the problem-solving process included: Initiation, Recollection, Conceptualization, and Conclusion. Researchers specified that a score of nine constituted a competent performance on any one problem.

The instruction in the control group was described as “the method used for the last ten years in Venezuela” (p. 254), and as being “characteristic of instruction in most high schools all over the world” (p. 254). In the treatment group, “content was sequenced such that the most inclusive, general principles were presented earlier in the instruction…” (p. 254), and there were “learning activities such as Concept Mapping and problem solving discussions” (p.254). While it was stated that Concept Mapping was involved within the treatment group, there is no indication of how it was used or how often. The problem-solving test was administered eight times over the course of the experiment, a different problem for each sitting.

There was no statistically significant effect of ability although this approached significance ($p<.08$). The results showed large effects in favor of the treatment group on every test administration and at all ability levels. No group’s performance reached the level of 9.0 that the authors claimed as “competent,” although some subgroups of the treatment group were getting close to this value at the end of the instruction. Some examples of scores from the high ability groups are provided here for illustration. On the first test, the high ability treatment group scored 3.23, and the high ability control group scored .50 By the final test, the scores were 8.86 and 4.28, respectively (Effect Size, test 8, approx. 2.6).

This study clearly represents a strong statement for the benefit of the instruction that was based on Ausubel’s (1968) learning theory and some sort of utilization of Concept Maps. Unfortunately, the nature of this instruction is not fully described. An additional notable finding is just how poor the performance was under the regular (control) instruction. This makes the reader curious about the nature and quality of instruction in these learning groups.

Studies in which Classes were Randomly Assigned to Conditions

Pankratius (1990)

Pankratius (1990) sought to test if Concept Mapping, and especially the *amount* of Concept Mapping, would affect achievement in physics problem solving. The main variable was the amount of Concept Mapping practice/experience the students were engaged in. The study was conducted in the US, with high school physics students, who were mostly seniors and a small number of juniors. Students were approximately 2/3 male. The average age was 17. The majority of students were “upper middle class.” The topic studied was conservation of energy and momentum. This was the sixth of seven units in the regular course. The main concepts covered were work, power, energy, and momentum.

The design included three conditions: a control and two kinds of treatment groups. Four classes were randomly assigned to the two treatment groups such that there were two classes in each treatment group. One class from each treatment received a pretest, exactly like the posttest. Another class just took the posttest. The experiment started with 145 students, but this number dropped to 87 for a variety of reasons. Achievement was evaluated using 30 items pertinent to the unit under study, selected from the Ontario Assessment Instrument Pool: Physics-Senior Division. This is an objective test used for assessment of high school physics achievement in Ontario.

The four classes in the treatments had six weeks of instruction on Concept Mapping prior to the experiment. This practice utilized physics content, e.g., general content of physics, and passages dealing with scientific law. These students had also submitted Concept Maps at the end of the two course units preceding the experiment, on the topics of forces, friction, torque, and two-dimensional motion. The control group received the course unit as usual, i.e., lectures, worksheets, reading and writing assignments, study guides, and labs. Students could work together in pairs or groups. One treatment group experienced the course unit as usual, but there was a requirement that students submit Concept Maps at the end of the unit. The second treatment group was required to make Concept Maps at the beginning of the unit (first or second day), and were encouraged to revise them throughout the course. Students in the treatment groups handed their maps in at the end of the unit. In both treatments, the teachers responded to individual queries about maps, but there was no large-scale, deliberate instructional focus on the mapping.

The results showed statistically significant differences, with both treatments performing better than the control, and periodic Concept Mapping being more effective than Concept Mapping just at the end of the unit. The effect size between periodic Concept Mapping and control was about 0.7. It should be noted that this effect amounts to approximately 3 points on the posttest. This study seems to have been fairly well designed and conducted. There are, however, a number of possible threats to validity:

- The extensive prior Concept Mapping during "practice" which utilized physics content,
- Non-randomization of participants (although the investigators did randomize classes), More time on task for the treatments (admitted by author), and
- High attrition rate (about 40%) for students.

Nevertheless, one might conclude that this study suggests some positive effect of Concept Mapping. It also suggests that sustained use of Concept Mapping is more effective than "one-shot," isolated interventions.

Czerniak & Haney (1998)

A study by Czerniak & Haney (1998) sought to test if the addition of Concept Mapping to instruction in a physical science course would improve achievement, reduce anxiety toward physical science, and reduce anxiety about teaching physical science at the elementary school level. The study was conducted in the US, using pre-service undergraduate education majors, and a physical science course taught in a teacher education school. The subject matter included electricity, magnetism, heat, light, sound, matter/energy, and basic mechanics. The design utilized a treatment condition and control, and pre- and post-testing. Of the four physical science classes taught in the school, two were randomly assigned to be the treatment and two the control. Students themselves were not randomly assigned to conditions. The study involved 104 females and 14 males, 58 in the experimental group and 60 in the control group.

A State Trait Anxiety Indicator was specially configured to measure three aspects of anxiety: general (trait) anxiety, anxiety about learning physical science, and anxiety about teaching physical science. Another instrument, Science Teaching Efficacy Beliefs, was used to measure self-efficacy for teaching physical science. Physical science achievement was measured using an internally constructed, 100 point measure, designed to cover the contents of the course.

Students in the treatment were introduced to Concept Mapping for two weeks before the start of the study. The investigators were careful not to include physical science concepts within this practice period. Rather, the students Concept Mapped topics such as items found in a grocery store. During the same period, students in control condition had two weeks of instruction on education reform. During the eight-week study, students in both conditions followed a structured, five-step teaching procedure, the BSCS Learning Cycle Model, which has the following components: engagement, exploration, explanation, elaboration, and evaluation. The only difference between the treatment and control groups was that students in treatment groups performed Concept Mapping during the explanation phase of this procedure. That is, in the treatment groups, small groups of three to four students first generated super- and subordinate concepts gleaned from steps prior to the explanation phase of the BSCS procedure. Then they met as a full class, generated concepts on the board, and then created a Concept Map from the items on the board.

ANCOVA was performed using the pretest results as the covariate, to help dilute any pretreatment differences in the students. The posttest was the dependent variable. The results showed that Concept Mapping increased achievement, decreased anxiety for learning physical science, and decreased general (trait) anxiety. It did not increase self-efficacy for teaching physical science. The effect size for achievement was approximately 0.7. This study was fairly well designed and conducted, e.g., the practice Concept Mapping was not contaminated by study of subject matter related to the experiment, and some steps were taken to minimize possible incoming differences among students

Concept Mapping was conducted in every lesson for the groups in the treatment, as an integral part of a structured approach to instruction. Hence, mapping was pervasive in the learning, as for instance in Pankratius (1990), which showed similar positive effects. Overall, the Czerniak & Haney (1998) study seems to be fairly trustworthy, showing moderate positive effects for Concept Mapping.

Jegede, Alaiyemola & Okebukola (1990)

The goal of Jegede, Alaiyemola & Okebukola (1990) was to test whether the addition of Concept Mapping to instruction would aid achievement and reduce anxiety (toward biology subject matter). The study was conducted in Nigeria, with students who were the American-equivalent of grade ten. This included boys and girls of ages 14 yr., 5 months to 18yr., 2 months. The context was a required course in biology. The particular subject matter of the unit within the course in which the experiment took place was nutrition in green plants and respiration in cells. The design of the study had two conditions, treatment and control, with pre and post-testing. There was random assignment of classes to conditions. That is, of five biology classes in the school, one each was randomly assigned to the treatment or control. (Students themselves were not randomly assigned to conditions.) There were 51 students in all (the treatment group had 14 M, 15F, and the control group had 16M, 6F).

Two instruments we used. To assess anxiety, Zuckerman's Affect Adjective Checklist was used. Achievement was tested with a 50-item multiple choice test selected from past West African Examinations' Council assessment examination papers. This test was validated by panel of biology teachers as appropriate for the subject matter of this course. The same test apparently was used as both the pre- and posttest, but this is not entirely clear.

The treatment group was familiarized to Concept Mapping for three weeks before the start of the study. It is difficult to determine what the students actually did during these three weeks. The report can be interpreted to mean that this instruction focused entirely on the philosophy and construction (practicing) of Concept Maps—and not on biology. It is not clear what the control group was doing during these same three weeks. The only statement in this regard is "The control group was introduced to the treatments's science concepts via expository teaching, which was devoid of any metacognitive strategy" (pp.953-954). During the six week study, "the experimental group was exposed to teaching that required each student to construct Concept Maps during each lesson. The control group did not carry out Concept Mapping but was taught using the lecture/expository approach" (p. 954).

The results were fairly dramatic in favor of Concept Mapping. There were positive Effect Sizes in favor of the Concept Mappers of 2.02 for achievement , and 1.01 for anxiety reduction. There are various aspects of this study that could make one wary. What exactly were the students doing during the three weeks of warm-up? What, in any detail, were they actually doing during the experimental phase? In addition, classes were randomized, not students. Another concern is with the control group. The changes from pre- to posttest seem quite large in the treatment group (over ten scale points), but there was essentially no change at all in the control group. As with Bascones & Novak (1985), one is left wondering about the nature and quality of the instruction within the control class.

Studies that Utilized Extant Methods of Instruction

Nicoll, Francisco & Nakhleh (2001)

The goal of a study by Nicoll, Francisco & Nakhleh (2001) was to investigate the value of using Concept Mapping in general chemistry and, more particularly, to see if Concept Mapping would produce a more interconnected knowledge base in students, compared to ordinary instruction. The study was conducted in the US and involved Purdue University college students, both men and women, in freshman-level general chemistry. This was a small-scale study, involving only twenty total students: Five males, five females in the control group, two males, eight females in the treatment group. The subject matter included electron bonding, electronegativity, and molecular geometry. The two groups were formed in the following way. Ten volunteers each from two different intact chemistry classes were recruited to participate. In one of these classes, Concept Mapping was normally and pervasively used, and students from this class constituted the treatment group. The other class was one in which Concept Mapping was not used at all, and students from this class formed the control. The authors claim that the extensiveness of the data analysis in their study prevented them from using the entire classes, rather than a subset of the students. There was an attempt to equate the participating students on various pertinent attributes, but the report indicates that the treatment group had more high school chemistry (1.6 yrs. vs. 1.1 years).

The experiment was conducted during one session of the ongoing courses. As noted, the study utilized classes that were normally taught in two different ways (i.e., there were no instructional changes made for the study to the way in which the courses were normally taught), one with traditional lecture etc., and one in which the teacher utilized Concept Mapping extensively, in just about all aspects of the course (e.g., conducted both by teacher and students, as part of lectures, demonstrations, tests, homework assignments). Hence, students in the Concept Mapping course already had extensive experience with Concept Mapping and did not need to be trained.

The study utilized a specially developed structured interview that was used at end of instruction to determine the degree of interconnectedness in a student's knowledge base. The structured interview was conducted with all of the students at the end of the instruction. The interview was designed to elicit concepts and relationships among them. The structured interview was used instead of Concept Mapping so as not to disadvantage the students who did not do the Concept Mapping.

The results showed that the Concept Mapping group knew more concepts (49 vs. 38), more linking relationships (69.9 vs. 46.2), more "useful" linking relationships (55 vs. 34.6), and had no more erroneous linking relationships than the non-Concept Mapping students. Despite some design flaws (e.g., non-random assignment, and more high school chemistry experience among the treatment group) these finding are very impressive for Concept Mapping, as it relates to the development of an interconnected knowledge base.

Studies in which an Alternative Educational Intervention was compared to Concept Mapping

Spaulding (1989)

A study by Spaulding (1989) addressed the effects of Concept Mapping versus "concept defining" on learning achievement in biology and chemistry. The study was conducted at a Florida public high school said to have average ability students. The subject matter was chemistry and biology, not further specified. The design involved two conditions, Concept Mapping and "concept defining" as the control. Four biology and two physics classes were assigned in equal numbers to the two conditions. It is not clear how this assignment was made. The biology classes involved 107 students, and the physics classes 44.

General aptitude (i.e., prior achievement) was measured by the CTBS (Comprehensive Test of Basic Skills) standardized test. To measure achievement , a test was constructed to cover the content to be addressed during the period of the study. This test is not described in any detail. The pretest (the CTBS) was administered one week in advance of the experiment. During the following week, the treatment groups were taught and practiced Concept Mapping. It is not stated what kind of material or subject matter was the topic for the practice.

The study utilized intact classes. All received their regular course of instruction. However, 15 minutes before the end of each class, groups in both conditions were given a set of concepts covered in the instruction. Concept Mappers were asked to Concept Map them, and "definers" were simply asked to define the concepts. (There is no specification of exactly what form this "defining" took.) Materials from both groups were then handed in and graded, and returned to students the next day. The achievement test was given at the end of three weeks. The results showed no differences between Concept Mappers and Definers. There was also no differential effect for chemistry vs. biology. The statistical interactions indicated that lower ability (as defined by the CTBS) students performed better with Concept Mapping, and higher ability students performed better when just defining the concepts.

Lehman, Carter & Kahle (1985)

Lehman, Carter & Kahle (1985) tested the effects of Concept Mapping (with Vee diagraming) vs. "outlining" on improving achievement in a biology course. The study involved inner-city African American students (about equal numbers of males and females) in high school biology in a school in Indiana. The specific subject matter was a section of a course that included materials of life, cell structure and function of cells, energy for life, and cell reproduction.

The design was a two condition, treatment and control, with pre- and post-testing. Ten intact classes, all introductory, were used--five experimental and five control. Achievement was measured with an internally constructed test, developed by project members. Items were assembled that were pertinent to the course, and stratified into Bloom's (1956) taxonomic levels (rote, comprehension, application, or above). Tests composed of thirty-two items were constructed from these, including only those items at the "comprehension" and "application" levels or above. Three such tests were used for pre-, post and follow-up tests (six weeks after experiment). There was also a special "relationships" test, constructed to assess understanding of relationships among concepts (also 32 items). All tests appear to have been multiple-choice.

The treatment group studied materials, viewed presentations, etc. and reviewed these using Concept Mapping and Vee diagramming. The control group did the same things but reviewed using outlining. During the pertinent section of the course, several of the review artifacts (outline or map) were submitted and graded.

This study compares Concept Mapping with an alternative educational intervention (cf. Spaulding 1989), in this case outlining. Both require students to actively engage, manipulate, and organize material. According to the authors, the key difference is that Concept Mapping accentuates relationships. Indeed, no statistically significant differences were found anywhere. All the Concept Mapping scores were higher, however, and the results on the "relationships" test were close to statistical significance ($p<.10$). Except for the relationships test, the differences were very small (mostly less than one item). The key to the success of both conditions might be the deliberate, structured, manipulative engagement with learning materials they engender.

Zittle (2002)

Zittle (2002) set out to determine the relative effectiveness in producing analogical transfer of studying text, studying a completed Concept Map, or filling in a blank, but structured Concept Map. The study was conducted in the US and included diverse college students solicited from the internet. The study itself was conducted over the internet. Four paired problem statements were constructed. These consisted of stories, containing an embedded problem to be solved. Each pair had the same logical argument structure but had a different cover story, i.e., different textual content, scenes, and participants. In this sense the paired problems were analogies of each other. Detecting the structural similaritity in the matched problems would greatly aid problem solving.

The study involved three groups. A solicitation to participate in the study was sent via the internet to individuals and organizations associated with distance based education. The main criteria for participation were that the volunteer be at least eighteen years old and be enrolled in a college or university. A large number of people (191) agreed to participate but a number of these were dropped for various reasons during the course of the study. Final group sizes were: Study Text 48; Study Concept Maps 42; SAFI (select and fill in Concept Maps l49).

In the "study" phase, participants studied and solved two problems, one from each matched pair, in the following manner. All three groups read the problem text. Then they studied the problem text under three different conditions. The text group studied the key points of the problem in text form. The Concept Map group studied the same points shown in the form of a completed Concept Map. The SAFI group studied using a structured Concept Map with links filled but the nodes blank, and were to fill in the content for the Concept Map. Then all groups attempted to solve the problems and were given incremental hints until they were successful. After a distractor task, the groups completed the transfer phase. That is, they conducted the same procedure they had for the first problems with the two remaining problems from the matched pairs.

The dependent variable was the number of hints required for solving the second problems. As was expected, and consistent with other studies, unaided transfer was rare; only 13 of 139 participants (9.4%) solved the problems with no hints. The text and Concept Map groups were nearly identical (requiring 7.3 vs. 6.2 hints respectively). The SAFI group required only half as many hints (3.4). This is a strong set of results. They are consistent with the interpretation that the greater learning resulted from more active, inquiring mental interaction with the learning materials in the SAFI group.

Coleman (1998)

The goal of a study by Coleman (1998) was to examine whether a "scaffolded explanation based intervention that uses procedural (explanation) prompts requiring students to explain, justify, evaluate, and contrast their personal knowledge with scientific knowledge promotes students' conceptual understanding of photosynthesis" (p. 391). The study was conducted in Canada, with 4th and 5th grade students, described as upper to middle-class. The subject matter was photosynthesis.

This study is unusual in that all the conditions used Concept Mapping, both as an assessment tool but also as a learning tool. The treatment involved some recurrent prompts that required the students to explain, justify, etc., the decisions they made while engaging with the Concept Mapping as a learning tool. That is, all groups did essentially the same thing. The difference had to do with the "explanation" requirement in the treatment group. The study investigated the concept of "intentional learning" (e.g., Bereiter & Scardemalia, 1989). Intentional learning involves an active, inquiry-based, approach to learning, which is often associated with enhanced learning outcomes.

A number of instruments were utilized. First, there was a problem solving or "intentional learning" instrument (the Individual Implicit Learning Theory Interview, LILTI). This is an instrument that measures degree of "intentional learning approach" employed by learners. The basic assumption was that students scoring high on this instrument would already be using active learning strategies associated with intentional learning. If these were introduced in the learning of lower scorers, the lower scorers could raise their learning achievement to the level of those scoring high on intentional learning.

Achievement was measured in three different ways. There was a Comprehension Test with multiple choice questions said to measure both declarative knowledge and higher-level "inferential knowledge." There was a Concept Mapping task, in which students were presented a set of concepts and were required to link up the concepts using a list of links generated by an expert and the researchers. There was also a Problem

Explanation Task, in which students were to try to explain some tricky and deep aspects of photosynthesis.

The study design involved two schools, with three groups at each school. Twelve students, six from each school, all scoring 80% or greater on the LILTI were assigned to the High Intentional Learning (HIL) Group. A remaining 36 were randomly assigned to the AI (Average Intentionality) or AC (Average Control) groups. Within all groups, students were randomly assigned to three-person small learning groups.

All students engaged a fairly sophisticated unit on photosynthesis, a unit which included inquiry, challenge of beliefs, small group work, etc. After two weeks and after four weeks, all students took part in the Concept Mapping task and the problem explanation task. They did the Concept Mapping first alone (which was then handed and graded) and then as consensus task in the three person sub-groups. They also conducted the explanation task in the sub- groups.

The treatment amounted to interspersing "intentional learning" type prompts in the work of the AI group. That is, in a number of ways, students were asked to explain, or justify, or relate, or evaluate, compare, contrast, and so on, aspects of their Concept Maps or their explanations. None of this prompting was done in the control groups.

The key result was that the "intentional learning prompts" did seem to have a beneficial effect, raising the performance in the AI group to that of HIL on most measures, including ones associated with basic comprehension, Concept Mapping and the explanation task. Since all of the groups were engaged in Concept Mapping, this study suggests kinds of facilitative strategies that may enhance the benefit of the Concept Mapping technique. It suggests that a benefit can derive from the acts of interacting, questioning, critiquing, explaining, evaluating, etc., among partners working on a Concept Map together (or alone).

Chang, Sung & Chen (2002)

A study by Chang, Sung & Chen (2002) sought to test the benefits for learning of three different kinds of uses of Concept Maps. The study was conducted in Taiwan, and involved 126 fifth grade students from an elementary school in Taipei. The subject matter comprised various topics in general science, e.g., "Knowing Typhoons," "Barrier of the Earth." Eight textual pieces on topics from general science were constructed. Seven of these were used in the course of the experiment as learning/study materials, and one was used as a posttest. Their length was said to range from 400-820 Chinese characters. The design involved four conditions, one control and three experimental, and a pre- and posttest. Four classes from a school were randomly assigned to the four conditions. The sizes of the four classes were 26, 32, 34, and 34.

Tests were chosen or created to assess text comprehension and text summarization ability. A standardized text comprehension measure, the Expository Text Comprehension Test, was used as a pretest. A separate text comprehension test was constructed as a posttest to avoid practice effects from the pretest. On these comprehension tests, items were classified as "text-based," i.e., the information for answering was contained directly in the presented text, and "inference," that required some sort of inference from what was actually presented. Separate tests for summarization quality were also constructed for use as the pretest and posttest. Roughly, the results from the summarization tests were "expressed in terms of summarization efficiency, the number of major idea units in the summary divided by the total word count in the summary" (p. 9).

Twice per week for four weeks, students read one of the science articles and studied it under one of the four conditions. In the Map Generation group, students constructed a Concept Map for the material from scratch. In the Map Correction group, students were given an "expert-generated" Concept Map for the material, in which some errors had been introduced. Students were to find and correct these errors. In the Scaffold-Fading group, students were progressively weaned from pre-constructed Concept Maps. That is, early in the set of science articles, they were given complete expert Concept Maps, later partially completed Concept Maps, and finally, no Concept Maps at all, just the original text from which they were to construct a Concept Map from scratch. The Control group received no adjuncts at all, just the original text to read and study.

The week before the experiment started, all treatment groups were introduced to the methods and theory of Concept Mapping. The meaning of "summarizing a text" was presented to all groups and students were given opportunity for practicing summarization. During these sessions, all groups completed the pretests. Scores on the pretests were used as covariates in the analysis of posttest results. For the next four weeks, all groups read and studied texts in a manner determined by their experimental condition, as described above. Total study time was equalized across the conditions. One week after the course was completed, the posttests were administered. This test utilized yet another scientific article, and students were *not* instructed to use the method of study they had used before.

The results showed that "the map-correction group did better on the (comprehension) posttest than the map-generation and control did, and the differences among the scaffold-fading, map-generation, and control group were not significant" (p.15). Noteworthy results in the summarization task were that the map-generation group scored no higher than the control, the map-correction group scored higher than the map generation and control, and that the scaffold-fading group was superior to the control group. The authors interpreted the results in terms of high "cognitive load" required for constructing a Concept Map from scratch, which might have left little mental capacity for learning. This contrasts with the intermediate load required in the map-correction procedure that, nonetheless, provides something of expert structure to the students while still requiring them to interact in an active, thoughtful way with the map provided. This raises the issue of how much training in Concept Mapping procedures is needed to possibly overcome the alleged effect of cognitive overload.

Studies that compared Concept Maps with other Forms of Learning Material

Hall & O'Donnell (1996)

The goal of Hall & O'Donnell (1996) was to test free recall memory of material presented as either text or as a Concept Map. The researchers also wanted to see if anxiety, motivation, and concentration were related to achievement. The study was conducted in an undergraduate psychology class in the US. The subject matter was relationships between the sympathetic and parasympathetic divisions of the autonomic nervous system. The design of the study involved two groups with a posttest. Students from the psychology class were assigned randomly to the two conditions. There was a total of 43 students, 22 experimental and 21 control.

The investigators created a graph-like instrument on which participants could rate their subjective anxiety, motivation, and concentration at various points of the procedure. Two sets of learning materials were created to describe relationships between the sympathetic and parasympathetic divisions of the autonomic nervous system. One was regular text, the other a Concept Map. Both contained approximately 1500 words.

Both the text and concept map groups studied a Concept Map on the differences between football and baseball . This was to familiarize all of students to Concept Maps. Following this, the two groups were told to study the experimental material (the Concept Map or the text) for 30 minutes. Two days later, both groups were given a free recall test. Exact wording was not required. The results were that the Concept Mapping group showed better recall for both superordinate and subordinate materials. The effect size for superordinates was about 0.5 and for subordinates about 1.2. The Concept Mapping group reported higher concentration and motivation. None of the subjective variables was related to achievement.

Hall, Hall & Saling (1999)

Two experiments by Hall, Hall & Saling (1999) sought to test effects of various "post-organization strategies," involving different ways of interacting with Concept Maps, for improving learning in students. The studies involved students in a US university undergraduate psychology course. The subject matter was relationships between the sympathetic and parasympathetic divisions of the autonomic nervous system.

The first experiment involved two groups, a treatment and control. Students taking the class were assigned randomly to the two conditions. There were a total of 90 participants. A Concept Map was created describing relationships between the sympathetic and parasympathetic divisions of the autonomic nervous system. This map contained approximately 1500 words. This map served as the study material in the experiment, as described below.

In the experimental procedure, both the treatment and control groups first studied a Concept Map on the differences between football and baseball, in order to become familiarized with Concept Maps. Following this, both groups were told to study the Concept map on the nervous system for 30 min. Following this, both groups continued to work for 15 more minutes. During this 15 minutes, control group students continued to study the prepared Concept Map in the same way they just had. In the treatment group, however, students wrote a summary of the learning material with a copy of the structure of the study Concept Map (nervous system) as a prompt (the links were labeled but the node content was blank)

Two days later, both groups were given a free recall test. Exact wording was not required. Propositions from the study map were classified as either superordinate (52 or 21% of the propositions) and subordinate (200, or 79% of the propositions). The results were that the treatment group scored significantly higher on recall for both super and sub-ordinate concepts, but clearly greater on superordinates. Effect sizes in favor of the treatment group were approximately 0.88 and 0.5 for the superordinates and subordinates, respectively

In the second experiment, the same basic procedure was followed. The main difference was that there were three groups. There was a "structure" group which studied with a Concept Map frame as in the experimental group of Experiment #1, a "map" group that wrote their summaries with the prompt of a fully completed Concept Map, and a "no cue" group that wrote their summaries with no cues at all. In addition to the free recall test conducted two days after the end of the experimental intervention, there was an additional test, i.e., summaries written in class were also scored for their accuracy

The results were that on concepts classified as superordinate, the "complete map" group scored higher than the "no cue group" on the in-class summaries. The "structure-only" group scored higher than the "no cue" group in free recall. There were no group differences regarding subordinate concepts. The authors claim more "significant effects" in their summary section than they report in their results section. However, the main point in both experiments is that Concept Maps as learning aids seem to have helped more for the recall of superordinates and that partially completed Concept Maps support learning better than either totally completed maps or no cuing at all.

Moreland, Dansereau & Chmielewski (1997)

The purpose of a study by Moreland, Dansereau & Chmielewski (1997) was to test the effectiveness on learning of "generating annotations," which are learner-generated enhancements of learning materials , including underlining, marginal notes, etc. These have found to be effective for learning in other studies, but here they were used for learning with Knowledge Maps (Knowledge Maps are very similar to Concept Maps except for more restriction on the nature of links and less restriction on the content of nodes in K-Mapping. See Chapter Three) as well as with standard text.. The study took place in the US, using undergraduate college students from a psychology course. The subject matter was Albert Einstein's personal and professional history.

The study employed a two condition design, a "map" condition and a "text" condition. Seventy-three students were recruited from the psychology course and were randomly assigned to the two conditions. Example Knowledge Maps were created for use in training students about Knowledge Maps. These Knowledge Maps were not about the experimental learning material, Einstein. The learning material to be used in the experiment condition was a large Knowledge Map (108 propositions) on the life and work of Einstein. A version of this material in standard text form was created for the control group. A number of instruments were used to obtain measurements on students' prior reading comprehension ability, vocabulary strength, etc.

The participants first participated in two sessions of training about Knowledge Mapping. (It is not clear whether groups from both experimental conditions participated in this training.) Knowledge Mapping was explained, demonstrated, practiced, etc. This training lasted about 30 minutes. After completion of training, participants studied the Einstein material in either text or map form for eight minutes. They were told they would be tested on this information. After this, participants were asked to spend eight minutes annotating either the text or Knowledge Map, i.e., to connect ideas, elaborate, underline, devise questions, and so forth. Annotations made by students were classified into four types, underlining/circling, making connections, making comments (elaborating), and creating questions. Finally, students were instructed to review their annotated maps for five minutes. Forty-eight hours later, all students attempted free recall of the material. They were instructed to write down everything they could recall from the study material.

There was no statistically significant difference on recall between the mapping condition and the text condition, although a difference in favor of the mapping group approached significance ($p<.08$). Regarding annotation forms, Knowledge Mappers produced significantly more connections, while those in the text group produced significantly more underlining/circling annotations. In both conditions, asking questions was a significant predictor of total score on the recall test. Making connections was a major predictor only for the mapping group. Underlining/circling and making comments was not a significant predictor for either group.

The authors note that the lack of difference in the recall task might be partly due to the unfamiliarity with Knowledge Maps for the students in the mapping group—the training was very brief, 30 minutes. Such an interpretation was also raised by Chang, Sung, & Chen (2002). The usefulness of annotation-like learning operations is reminiscent of the kinds of facilitation operations (e.g., "connect," "explain") that were found to enhance learning with Concept Maps in Coleman (1998).

Rewey, Dansereau, Dees, Skaggs & Pitre (1989)

The purpose of a study by Rewey, Dansereau, Dees, Skaggs & Pitre (1989) was to test the effects on learning of the format of supplemental materials, i.e.," knowledge mapping" vs. text. vs. no supplement, across three styles of instruction: cooperative learning vs. cooperative teaching vs. individual study. The study involved undergraduate students in a psychology course at a US college. The subject matter was the biology of the autonomic nervous system and statistics (probability).

Two main instructional instruments were created. An instructional text was created for both the autonomic nervous system and for the material on probability. These would be the main learning materials for the students in the experiment. Both passages were about 1500 words long. Two supplemental materials were also created. One was a Knowledge Map (very similar to a Concept Map) of the study materials, and one was a textual summary of the main concepts in the instructional text. Tests composed of fifteen multiple choice items were created for each topic for use as an achievement test. The Delta Reading Vocabulary Test was used as a measure of prior verbal aptitude. The design included format of the supplemental material and the three styles of instruction. One hundred eighty-six students volunteered for the study. Sixty-four percent were women. Average age was 18-19 years. Students (after volunteering) were randomly assigned to conditions.

The study was conducted in three 75 minute sessions. In Session 1, students took the Delta test and received twenty minutes of instruction about Knowledge Maps. Session 2 was also a practice session in which students participated in a dry run of the actual experiment, using the same procedures they would use later, but engaging different subject matter as learning material (i.e., the "circulatory system" and "measures of central tendency" from statistics). In Session 3, the main experiment, students studied first the "autonomic" passage and after that the "probability" passage in a second session. Students in the cooperative groups studied in pairs. The supplemental material—the summary text or the Knowledge Map—were supplied to aid the study of the passage. All groups were given 20 minutes to study and 10 minutes to review or interact cooperatively. In Session 4, students were given free recall tests for both passages and also completed the multiple-choice achievement tests.

Two major results were that the Knowledge Mapping groups did not outperform the other supplement groups, although trends in that direction were apparent. Neither did the cooperative groups outperform the students who worked alone. One major finding was that for low ability students (as measured by the Delta test), a cooperative learning method with Knowledge Mappinga aided learning in comparison to the other conditions. High ability students did not differ among any of the conditions. As in Schmid & Telaro (1990), the authors speculate that Knowledge Mapping may induce lower ability students to engage in learning practices that higher ability students already utilize. The very short training about Knowledge Mapping may have contributed to the lack of overall effect for this method. (see also Chang, Sung, & Chen, 2002; Moreland, Dansereau, & Chimielewski, 1997).

Summary

These studies allow us to sketch some patterns of use that appear to enhance the learning effectiveness of Concept Mapping. First, when Concept Mapping is used in a course of instruction, it is better that it be an integral, on-going feature of the learning process, not just some isolated "add-on" at the beginning or end. In this regard, Concept Mapping appears to be particularly beneficial when it is used in an on-going way to consolidate or crystallize educational experiences in the classroom, for example, a lecture, demonstration, or laboratory experience. In this mode, learners experience an educational event and then use Concept Mapping in a reflective way to enhance the learning from the event. There is also indication that learning effects are enhanced when in the course of Concept Mapping learners adopt an active, deep and questioning approach to the subject matter. Such active, self-engaging , transformational interaction with learning material has been suggested to enhance learning in general (e.g., (Feltovich, Spiro, & Coulson, 1993) and this appears to carry over to learning with Concept Maps as a tool. This kind of interaction can be engendered by a teacher/facilitator who challenges the learner to, for example, explain, justify, and formulate questions in the course of building a Concept Map. It can also be induced by the nature of the concept Mapping task itself, as when learners are to find and correct the errors in an “expert’s” map.

When Concept Mapping is compared with other sorts of activities, such as outlining or defining concepts, that also can induce the learner to take a thoughtful, systematic approach to engaging subject matter, the positive benefit of Concept Mapping often diminishes (a finding noted also in the review by Horton, 1993). However, even in these situations, it appears that Concept Mapping is especially good, in comparison to other interventions, for the learning of *relationships* among concepts.

From several of the studies reviewed, there is indication that Concept Mapping may be particularly beneficial for lower ability learners, partly because it does induce the active, inquiring, orderly approach to learning that is likely a more natural part of the higher ability student’s approach to learning. On the other hand, when learners *are not yet facile* with constructing Concept Maps, there is some indication that the cognitive load of creating maps from scratch may hinder learning. When students are novice mappers, other “scaffolded” ways of interacting with Concept Maps, for example, filling in the blank content nodes of a concept Map already containing the labeled relationships of a completed Concept Map, may be beneficial.

Finally, the degree of facility with the Concept-Mapping procedure necessary to optimize the benefits of constructing Concept Maps from scratch is an issue open for investigation.