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Theoretical Origins of Concept Maps, How to Construct Them, and Uses in Education [1]

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ABSTRACT

Concept maps, as we define them, are graphical tools for organizing and representing relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts. Concepts and propositions are usually organized hierarchically, from most general, most inclusive to most specific. 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 knowledge in the form of a concept map, thus providing the context for the concept map.

In this paper we briefly present the origins and theoretical foundations of concept maps, explain how concept maps are constructed, and then show how the integration of concept maps with technology in software such as CmapTools facilitates the implementation of concept map-based learning environments that support our New Model for Education. Last, examples from three domains are used to describe how concept maps can be used to organize content based on the knowledge of domain experts, creating an environment that is easy to navigate for learners.

ORIGIN OF CONCEPT MAPS

Concept maps were developed in 1972 in the course of Novak's research program at Cornell University where he sought to follow and understand changes in children's knowledge of science (Novak & Musonda, 1991). During the course of this study the researchers interviewed many children, and they found it difficult to identify specific changes in the children's understanding of science concepts by examination of interview transcripts. This program was based on the learning psychology of David Ausubel (1963; 1968; Ausubel *et al.*, 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*. Out of the necessity to find a better way to represent children's conceptual understanding emerged the idea of representing children's knowledge in the form of a *concept map*. Thus was born a new tool not only for use in research, but also for many other uses. Figure 1 shows a concept map that illustrates the key features of concept map.

[1] Modified and abridged from Novak and Cañas (2006).

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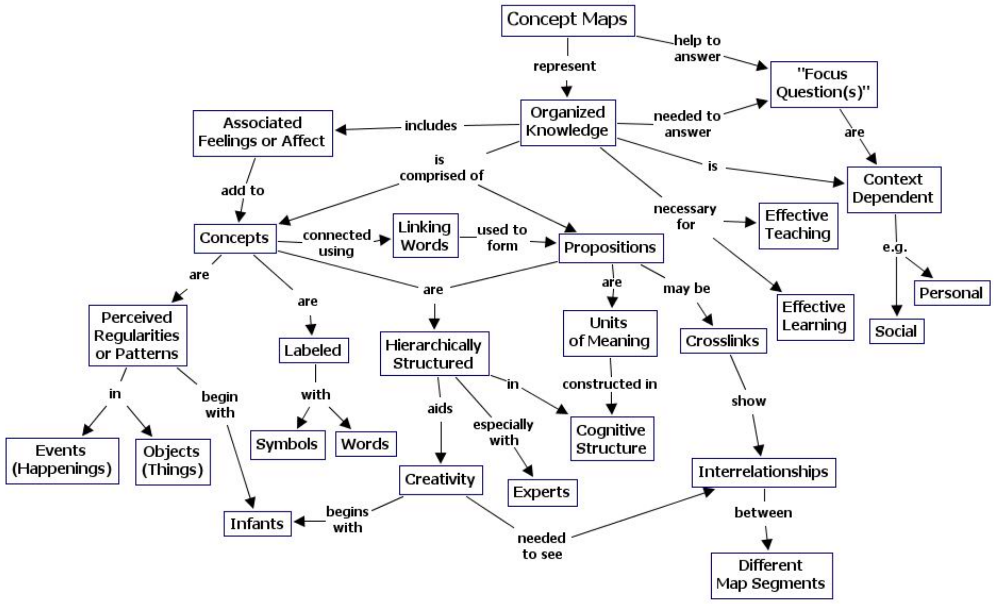

Figure 1: A concept map showing the key features of concept maps

PSYCHOLOGICAL FOUNDATIONS OF CONCEPT MAPS

The question sometimes arises as to the origin of our first concepts. These are acquired by children during the ages of birth to three years, when they recognize regularities in the world around them and begin to identify language labels or symbols for these regularities (Macnamara, 1982). This early learning of concepts is primarily a *discovery learning* process, where the individual discerns patterns or regularities in events or objects and recognizes these as the same regularities labelled by older persons with words or symbols. This is a phenomenal ability that is part of the evolutionary heritage of all normal human beings. After age 3, new concept and propositional learning is mediated heavily by language, and takes place primarily by a *reception learning* process where new meanings are obtained by asking questions and getting clarification of relationships between old concepts and propositions and new concepts and propositions. This acquisition is mediated in a very important way when concrete experiences or props are available; hence the importance of "hands-on" activity for science learning with young children, but this is also true with learners of any age and in any subject matter domain.

In addition to the distinction between the discovery learning process, where the attributes of concepts are identified autonomously by the learner, and the reception learning process, where the attributes of concepts are described using language and transmitted to the learner, Ausubel made the very important distinction between *rote learning* and *meaningful learning*. 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. (2) The learner must possess relevant prior knowledge. (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 nature of the indirect control which instructors have to encourage meaningful learning lies primarily in the instructional strategies used and the evaluation strategies used. Instructional strategies that emphasize relating new knowledge to the learner's existing knowledge foster meaningful learning, as do evaluation strategies that encourage learners to use ideas they possess for solution of novel problems. Typical objective tests seldom require more than rote learning (Holden, 1992). In fact, the worst forms of objective tests, or short-answers tests, require verbatim recall of statements and this may be impeded by meaningful learning where new knowledge is assimilated into existing frameworks, making it difficult to recall specific, verbatim definitions or descriptions. This kind of problem was recognized years ago in Hoffman's (1962) The Tyranny of Testing.

People often confuse rote learning and meaningful learning with teaching approaches that can vary on a continuum from direct presentation of information (which may be conceptually obscure or conceptually explicit) to autonomous discovery approaches where the learner perceives the regularities and constructs her/his own concepts. Both direct presentation and discovery teaching methods can lead to highly rote or highly meaningful learning by the learner, depending on the disposition of the learner and the organization of the instructional materials. There is the mistaken notion that "inquiry" studies will assure meaningful learning. The reality is that unless students possess at least a rudimentary *conceptual* understanding of the phenomenon they are investigating, the activity may lead to little or no gain in their relevant knowledge and may be little more than busy work (Mayer, 2004).

One of the powerful uses of concept maps is not only as a learning tool but also as an evaluation tool, thus encouraging students to use meaningful-mode learning patterns (Mintzes et al., 2000; Novak, 1990; Novak & Gowin, 1984). Concept maps are also effective in identifying both valid and invalid ideas held by students. 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). Moreover, when learners work with concept maps, they become more proficient at meaningful learning and they can overcome misconceptions they held initially (Novak, 2002).

One of the challenges teachers face is how to organize the curriculum optimally to facilitate meaningful learning. When a teacher develops her/his own concept maps for a domain of study, the teacher gains a clearer understanding of the key concepts to be learned, and the concept map also provides guidance for the learning sequence. Working through the concepts on the map, from the more general, more inclusive concepts at the top of the map to the more specific, concepts lower in the map provides for a psychologically sound sequencing of instruction. The early acquisition of more general concepts provides anchorage or scaffolding for subsequent learning for more detailed, more specific concepts and principles. It is also possible to use concept maps to see how a given state or local curriculum matches or deviates from an optimal leaning sequence, and/or includes or omits necessary concepts. Heinze-Frey & Ludwig (2006) have done a good illustration of this for a section of the curriculum dealing with the environment for Lexington Public schools, as shown in Figure 2. Their concept map also illustrates how an instructional sequence that proceeds from the top down the map could optimize meaningful learning.

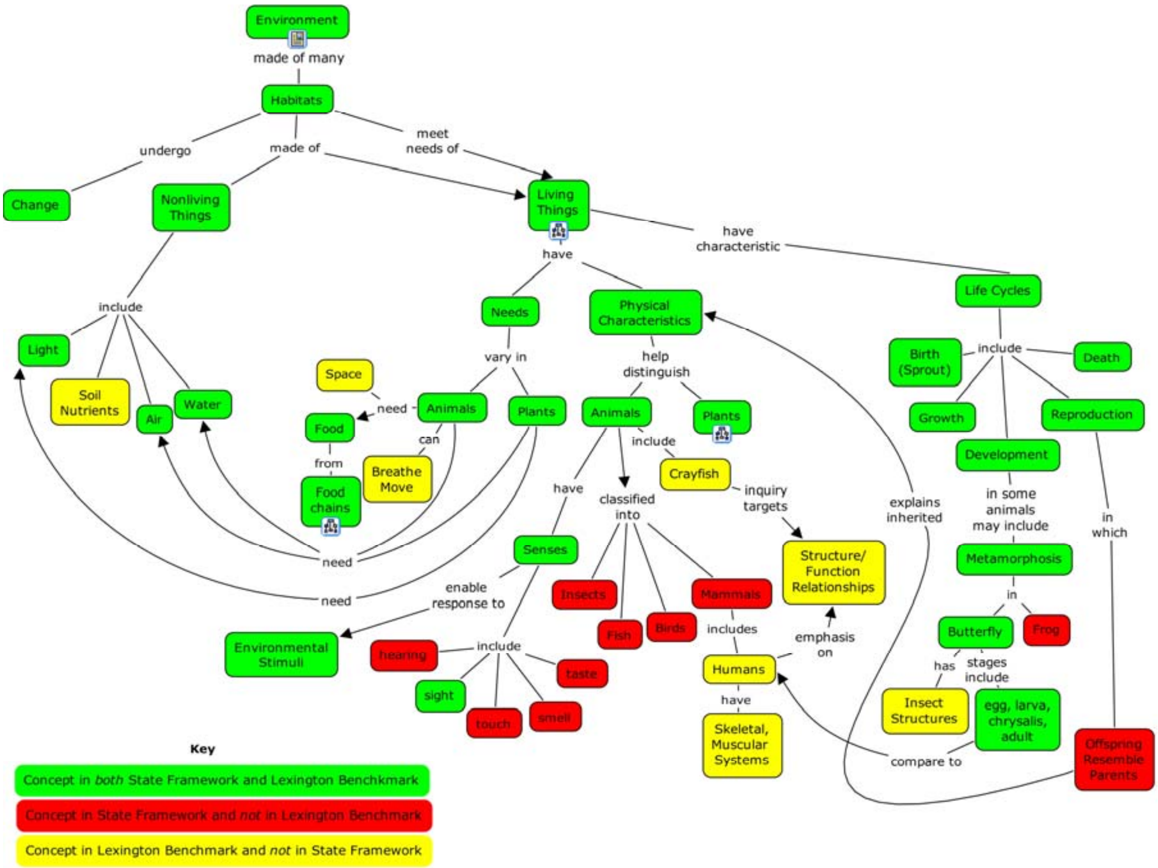

Figure 2: A concept map showing similarities and differences in the State and local curriculum dealing with the area of environment

Many learners and teachers are surprised to see how this simple mapping tool facilitates meaningful learning and the creation of powerful knowledge frameworks that not only permit utilization of the knowledge in new contexts, but also the retention of the knowledge for long periods of time (Novak, 1990; Novak & Wandersee, 1991). There is still relatively little known about memory processes and how knowledge finally gets incorporated into our brain, but it seems evident from diverse sources of research that our brain works to organize knowledge into hierarchical frameworks and that learning approaches that facilitate this process significantly enhance the learning capability of all learners (Bransford *et al.*, 1999).

While it is true that some students (and some teachers) have difficulty building concept maps and using these, at least early in their experience, this appears to result primarily from years of rote-mode learning practice in school settings rather than as a result of brain structure differences per se. So-called "learning style" differences are, to a large extent, derivative from differences in the patterns of learning that students have employed varying from high commitment to continuous rote-mode learning to almost exclusive commitment to meaningful mode learning. It is not easy to help students in the former condition move to patterns of learning of the latter type (Kinchin, 2001). While concept maps can help, students also need to be taught something about brain mechanisms and knowledge organization, and this instruction should accompany the use of concept maps. The information in the above paragraphs should become part on the instructional program for skilful use of concept maps. The information provided in this paper could be part of this instruction.

EPISTEMOLOGICAL FOUNDATIONS OF CONCEPT MAPS

As shown in Figure 1, we defined concept as a *perceived regularity (or pattern) in events or objects, or records of events or objects, designated by label*. It is coming to be generally recognized now that the meaningful learning processes described above are the same processes used by scientists and mathematicians, or experts in any discipline, to construct new knowledge. In fact, Novak has argued that new *knowledge creation* is nothing more than a relatively high level of meaningful learning accomplished by individuals who have a well organized knowledge structure in the particular area of knowledge, and also a strong emotional commitment to persist in finding new meanings (Novak, 1993; 1998). *Epistemology* is that branch of philosophy that deals with the nature of knowledge and new knowledge creation. 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, 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 foster creative thinking or novel problem-solving.

We hear much today about constructivism and constructivist teaching. The fundamental idea behind constructivism is that each person must build her/his own understanding; the teacher cannot install knowledge into the learner's head. The latter idea is basically a psychological idea, and there is also an epistemological aspect of constructivism that is less often emphasized. In contrast to the dominant *positivist* epistemology of the first half of the 20^{th} Century, constructivist epistemology sees knowledge not as discovered absolute truths but rather knowledge is seen as a human construction that evolves as new ideas and new ways of looking at the world evolve. Here again we see the parallel between how people learn and how they construct knowledge. We shall see in the New Model for Education discussed below how concept maps can facilitate both new learning and new knowledge creation.

CONSTRUCTING GOOD CONCEPT MAPS

In learning to construct a concept map, it is important to begin with a domain of knowledge that is very familiar to the person constructing the map. It is also important to define the area of knowledge to be mapped, and this is done best by preparing an appropriate *focus question*, or a question that will be answered by the knowledge that is mapped. Usually focus questions that require explanation, rather than simple description or classification, lead to better concept maps. Recall that concepts are constructed to code regularities in events or in objects. Generally speaking, focus questions that call for more event explanations require deeper, more meaningful thinking than those that describe object characteristics (Derbentseva *et al*, 2006). Examples of better and poorer focus questions are given below:

<u>Good focus questions:</u>

Why do we have seasons?

How can we help teachers become more effective?

How would you explain what Poe was trying to illustrate in this short story?

<u>Less Useful Focus Questions:</u>

What are the key features of a flower?

What are common traits of effective teachers?

Given a selected domain and a defined question or problem in this domain, the next step is to identify the key concepts that apply to this domain. Usually 15 to 25 concepts will suffice. These concepts could be listed, and then from this list a rank ordered list should be established from the most general, most inclusive concept, for this particular problem or situation, to the most specific, least general concept. Although this rank order may be only approximate, it helps to begin the process of map construction. We refer to the list of concepts as a parking lot, since we will move these concepts into the concept map as we determine where they fit in. Some concepts may remain in the parking lot as the map is completed if the mapmaker sees no good connection for these with other concepts in the map.

The next step is to construct a preliminary concept map. This can be done on a sheet of paper or by writing all of the concepts on Post-its, or preferably by using the IHMC CmapTools (Cañas *et al*., 2004) computer software program described below. Post-its allow a group to work on a whiteboard or butcher paper and to move concepts around easily. This is necessary as one begins to struggle with the process of building a good hierarchical organization. Computer software programs are even better in that they allow moving of concepts together with linking statements and the moving of groups of concepts and links to restructure the map. When CmapTools is used in conjunction with a computer projector, two or more individuals can easily collaborate in building a concept map and see changes as they progress in their work. CmapTools also allows for collaboration between individuals in the same room or anywhere in the world, and the maps can be built synchronously or asynchronously, depending on the mapmakers' schedules.

It is important to recognize that a concept map is never finished. After a preliminary map is constructed, it is always necessary to revise this map. Other concepts can be added. Good maps usually result from three to many revisions. This is one reason why using computer software is helpful.

Students often comment that it is hard to add linking words onto the "lines" of their concept map. This is because they poorly understand the relationship between the concepts, or the meanings of the concepts, and it is the linking words that specify this relationship. Once students begin to focus-in on good linking words, and on the identification of good cross-links, they can see that every concept could be related to every other concept. This also produces some frustration, and they must choose to identify the most prominent and most useful cross-links. This process involves what Bloom (1956) identified as high levels of cognitive performance, namely evaluation and synthesis of knowledge. Concept mapping is an easy way to encourage very high levels of cognitive performance, when the process is done well. This is one reason concept mapping can also be a very powerful evaluation tool (Edmondson, 2000).

CmapTools provides for the linking of any kind of digital resource (e.g. images, photos, videos, URLs, PDFs, other concept maps, etc.) to a concept or linking phrase to create in effect a knowledge portfolio or a knowledge model. To link a resource to a concept map, one only needs to drag that resource and drop it onto a target concept. The digital resource is now linked to the concept map and can be reached through the icon under the target concept.

Finally, the map should be revised, concepts re-positioned in ways that lend to clarity and better over-all structure, and a "final" map prepared. When computer software is used, one can go back, change the size and font style, and add colours to "dress up" the concept map.

Through the storing of concept maps in CmapServers, CmapTools encourages collaboration among users constructing the maps. When maps are stored in a server on the Internet, users with appropriate permissions (Cañas *et al.*, 2003) can edit shared concept maps at the same time (synchronously) or at their convenience (asynchronously). "Discussion threads" and "Annotations" in the form of electronic "Post-It" notes can be used to make anecdotal comments on concept maps or during map construction. The high degree of explicitness of concept maps makes them an ideal vehicle for exchange of ideas or for the collaborative construction of new knowledge. We have also found that the obstacles deriving from personal insecurities and fear of embarrassment are largely circumvented, since critical comments are directed at the concept map, not at the person(s) building the map. Having learners comment on each other's concept maps, whether they are in the same classroom or in different schools, is an effective form of peer-review and collaboration.

A NEW MODEL FOR EDUCATION

A Concept Map-Centred Learning Environment

CmapTools provides a variety of features that make it possible for teachers to use concept maps for a variety of the tasks that students perform (Cañas & Novak, 2005). In addition to a network environment that fosters collaboration and the possibility of constructing knowledge models, the software allows users, among other features, to (a) search for information based on a concept map (Carvalho *et al.*, 2001), by which a student can use the Cmap to research information to learn more about the topic, leading to an improved map with linked resources, and iteratively proceed on another search; (b) record the process of constructing a Cmap for later playback, providing support to the teacher in what is considered to be a key aspect of concept mapping: the process of constructing a map; (c) piece-wise display a concept map and associated resources full-screen for oral presentations; (d) graphically compare two Cmaps, allowing the teacher to compare the student's map to his/hers for an initial evaluation. The concept map can thus become an artefact around which the various activities of the learning process can be centred, as shown in Figure 3.

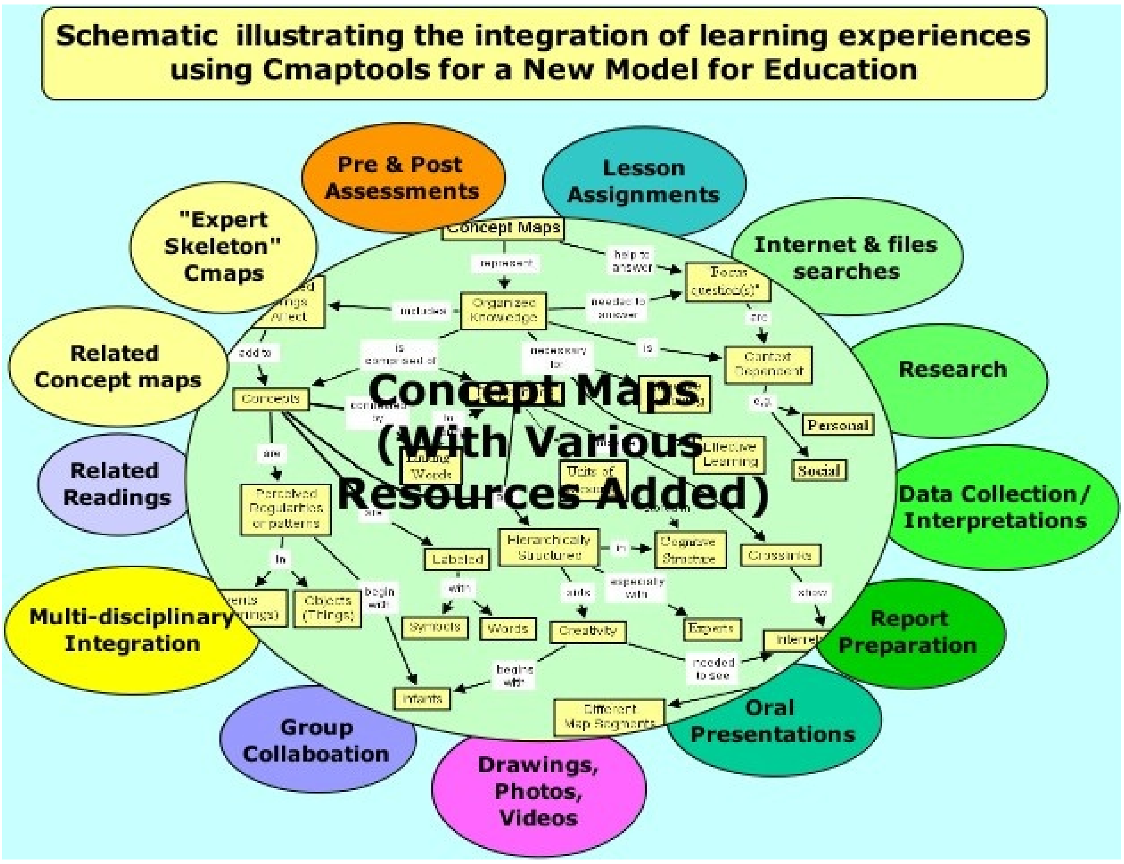

Figure 3: A concept map can serve as the scaffold for building a knowledge portfolio combining all the various kinds of learning activity that can be added in digital form

Based on the features provided by CmapTools described above, the student can use the concept map prepared as a pre-test as an initial step towards learning the pieces of knowledge that he/she needs to better understand, as the basis on which to perform the research that leads to this understanding, as a way to organize the various sources from which the student will construct this understanding, as the artefact with which to collaborate with peers, and as the means to present his/her findings at the end of the unit. Furthermore, the concept maps constructed by the student can become the foundation for a portfolio evaluation (see Vitale & Romance, 2000) of his/her performance.

CONCEPT MAP-BASED TRAINING AND PERFORMANCE SUPPORT

Systems that embody the knowledge and reasoning capabilities of experts in the performance of skilled tasks hold the promise of providing much greater utility than current training programs provide. The goal, as Wehrenberg (1989, p 38) aptly expressed it is "to put the right person in the right place at the right time with the right skills ..." Creating systems that embody the knowledge of experts require the capturing, representing and sharing of the experts' knowledge in a form that can be taking advantage of by learners. Concept maps have been used successfully for many years as a knowledge elicitation technique (Ford *et al.*, 1991, Coffey *et al.*, 2002), and at IHMC we have used them to construct training and performance support systems for a variety of domains. In this section we briefly describe three of these systems: NUCES, El-Tech and Mars 2001 as examples of how the knowledge of experts can be captured and shared with learners through concept maps.

Nuces: Nuclear Cardiology Expert System

Nuces (Nuclear Cardiology Expert System) is a prototype diagnostic expert system based on first pass functional imaging of the heart (Ford *et al.*, 1996). Concept maps were used to elicit the expert's knowledge, and at the same maps later became the explanation component of the system as shown in Figure 4. The concept maps are linked to all types of resources (including other concept maps, videos of the expert, images, documents, research papers, WWW pages, etc.) that can be reached through the icons underneath the various concepts. By navigating through the concept maps, each learner can choose a personal path to follow that depends on the information being sought. Using the expert's knowledge as a means to organize content leads to an easier navigation and searching of information (Carnot *et al.*, 2001).

El-Tech: Electronic Technician

Nuces showed that the knowledge of a medical doctor could be captured through concept maps and integrated into a knowledge model that allowed individual learners to navigate through a large collection of resources. El-Tech (Electronic Technician) (Coffey *et al.*, 2003), developed in a joint research effort with the Chief of Naval Education and Training of the US Navy, demonstrated that the same mechanism is possible at the technical level: it captures the expertise of an expert electronics technician on the RD-379A(V)/UNH, a fault-tolerant magnetic recorder/reproducer manufactured by Magnasync/Moviola corporation.

Mars 2001

Briggs *et al.* (2004) report on the use of concept mapping to create Mars 2001, a collection of over 100 concept maps created at the Center for Mars Exploration at NASA Ames, that is used to navigate over a huge collection of resources on the WWW[2]. Students of all ages navigate through the concept maps as a way to both learn from the expert's knowledge and to reach the diverse media that are linked to the concept maps. Mars 2001 is an excellent example of how concept maps can be used to organize content in a non-linear fashion, using the expert's knowledge as the organizational structure, truly standing in the shoulders of giants in the creation of these knowledge models. Of particular interest is the fact that in the case of Mars 2001, the expert (Dr. Geoff Briggs) constructed the maps himself (and with some help from colleagues) and there were no knowledge elicitation sessions and maps constructed by knowledge engineers, as was the case of Nuces and El-Tech.

SUMMARY

We have introduced concept maps as a tool to represent and share knowledge, explaining briefly their theoretical foundations and how to construct concept maps. We then presented how to take advantage of the integration of concept maps with technology, as exemplified by CmapTools, as a means to provide a concept map-centred learning environment that supports a New Model of Education. Last, we briefly presented three different domains where concept maps have been used to construct a training/learning environment, whereby the concept maps facilitate the construction of a non-linear navigation mechanism through which learners easily reach the information they are seeking.

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[2] The Mars concept maps can be reached at http://cmex.ihmc.us.

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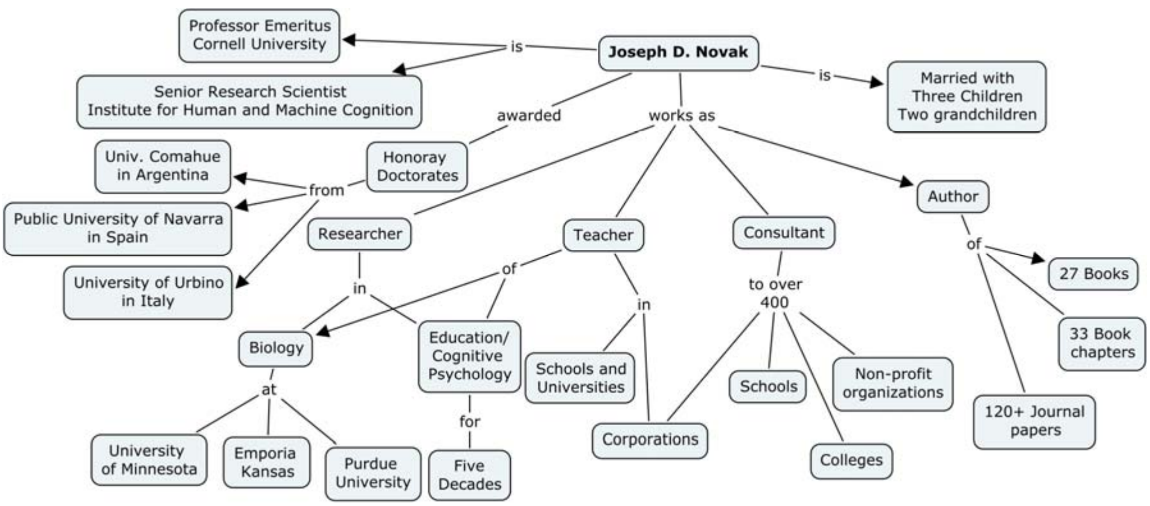

Completing graduate studies at the University of Minnesota in 1958, Dr. Novak taught biology at Kansas State at Emporia, and Purdue University. From 1967 to 1995, he was Professor of Education and Biological sciences at Cornell University where his research focused on human learning, educational studies and knowledge creation. He is currently Professor Emeritus, Cornell University and Senior Research Scientist at the Institute for Human and Machine Cognition, Univ. of West Florida. He is author or co-author of 27 books and more than 130 book chapters and papers in professional books and journals. He has consulted with more than 400 schools, universities and corporations, including recent work with Procter and Gamble, and NASA. His recent book, 'Learning, creating, and using knowledge: concept maps as facilitative tools in schools and corporations', (LEA., 1998) is currently being translated into five foreign languages. Dr. Novak is listed in Who's Who in America, and other lists, and has received a number of awards and honours including Honorary Doctorates from The University of Comahue in 1998 in Nuquen, Argentina, and The Public University of Navarra in 2002 in Pamplona, Spain and the University of Urbino in Urbino, Italy in 2006. He received the first award for contributions to science education from the Council of Scientific Society Presidents. His current research work includes studies on students' ideas on learning and epistemology, and methods of applying educational ideas and tools (such as concept mapping for knowledge archiving and utilization) in corporate settings, schools, universities and distance learning. He is married with three children and two grandchildren.

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For many years, Dr. Cañas has been involved in the use of computers in education, with particular interest in understanding the pedagogical aspects of using technology, and leveraging on his Computer Science background to come up with innovative solutions. He is interested not only in the theoretical aspects, but also in the implementation details and scalability of computers in education efforts. He has been a consultant to Presidents of Costa Rica and Panama in the large scale introduction of computers into the public school systems, resulting in the creation of the Omar Dengo Foundation in Costa Rica and the Conéctate al Conocimiento Project in Panama. He directed the Quorum Project while at the Univ. of West Florida, a joint effort with IBM Latin America that led to the creation of a computer network that allowed thousand of students in schools throughout seven countries in the Americas to have their own email address and work on collaborative projects before Internet arrived in those countries. At IHMC, with the support of NASA and the US DOD, he has led the development of CmapTools, a software suite to represent and share knowledge models that is used by students and professionals in over 150 countries.

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