THE UNIVERSALITY AND UBIQUITOUSNESS OF CONCEPT MAPS

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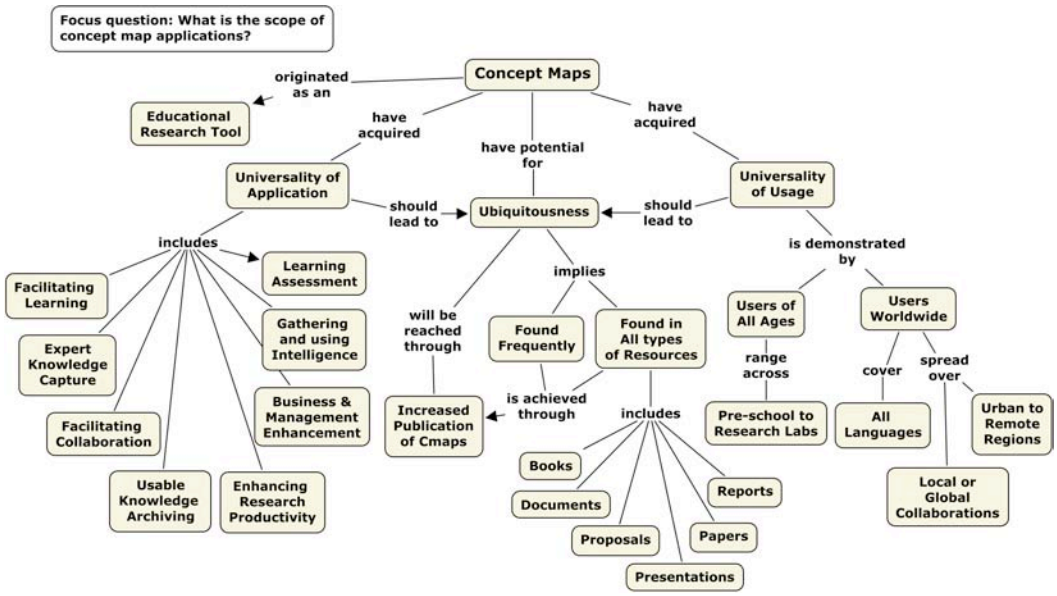

1 Introduction: The Origins and Evolution of the Concept Mapping Tool[1]

The concept map was developed as a response to the necessity by Novak's research group at Cornell University in the early 1970s to find a better way to represent children's conceptual understandings and to be able to observe explicit changes in the concept and propositional structures that construct those understandings, as part of a 12-year longitudinal study following a 2-year instructional period using audio-tutorial instruction in grades one and two (Novak, 1972). The research program was based on Ausubel's (1963, 1968) Assimilation Theory of cognitive learning, and an emerging constructivist epistemology that viewed knowledge as a human creation involving the construction on new concepts and propositions through the process of high levels of meaningful learning, as described by Ausubel, and Novak's Human Constructivist epistemology (Novak, 1993, 1998). While we found structured interviews to be useful in capturing children's understanding, it was difficult to discern specific changes in the children's concept and propositional ideas as they progressed through schooling. Working with a talented group of graduate students, Novak and his colleagues came up with the idea of transforming interview transcripts into a hierarchically arranged set of concepts and propositions representing the knowledge expressed in the interview. Mapping a child's interview transcript often revealed ambiguities not seen previously that required more careful listening to the interview tape to discern additional cues for the child's thinking. Thus was born the concept map tool for representing human knowledge.

1.1 Expansion of the Use of Concept Maps in Education

Graduate students in Novak's research group soon discovered that concept maps were not only useful to transcribe the children's' interviews, but helped them become better learners. It became increasingly apparent that *meaningful learning was the most important factor in building powerful knowledge structures,* and by contrast, learning by rote contributed little to building individual's knowledge structures, nor does rote learning result in the remediation of misconceptions held by learners. Novak found that the use of concept maps could help students *learn how to learn*

[1]For a description of the origins of concept mapping see Novak & Cañas (2006).

meaningfully, and taught a course at Cornell University for 20 years to help students become better learners. This course led to the book, *Learning How to Learn* (Novak & Gowin, 1984) now published in 9 languages.

During the 1980s concept mapping's popularity flourished particularly within the education community, in conjunction with Ausubel's Assimilation Theory. Concept maps became a popular assessment tool, from elementary school to graduate courses. However, concept maps were mainly drawn on paper by hand, which limited their use since it would take a big effort to redo concept maps, and so they were seldom redrawn. The potential of the concept mapping tool was not yet fully realized.

1.2 Concept Mapping meets the Internet & Corporations

Advances in graphical user interfaces and technologies in the 1990's allowed the development of computer-based concept mapping editors. But it was the development of concept mapping tools, such as CmapTools (Cañas, Hill, et al., 2004), that leveraged the Web, multimedia and Internet that further expanded the use of concept mapping, not only in terms of users but also the types of applications to which it applied and organizations that use it. These new tools enabled the collaborative construction of concept maps, and publishing and sharing of concept maps on the Web. The ability to easily link concept maps to other concept maps, and link different types of resources (images, videos, texts, Web pages, etc.) to the maps allowed the construction of Knowledge Models (Cañas, et al., 2005) enabling the representation of more complex domains and the development of a concept map-centered learning environment: a New Model for education (Novak & Cañas, 2004).

In the 1990's, Novak worked with R&D staff at Procter and Gamble and found that concept mapping not only facilitated better organization of research team's knowledge, but also facilitated creative work by the team. These works are summarized in *Learning, Creating, and Using Knowledge: Concept maps as Facilitative Tools in Schools and Corporations* (Novak, 1998). In all of this work the most fundamental idea is that meaningful learning not only helps learners acquire more powerful knowledge structures, but it is also the means for the creation of new knowledge.

The 2000's have seen a continuous growth in the use of concept mapping and in its applications. This growth is reflected in the extensive participation and wide-ranging topics presented at the Concept Mapping Conferences (Cañas & Novak, 2006a; Cañas, Novak, & González, 2004; Cañas, Reiska, Åhlberg, & Novak, 2008) and in the active Cmappers community (the informal community of concept mappers around the world). Figure 1 shows how CmapTools users connecting to CmapServers cover large portions of the world.

Figure 1. CmapTools users throughout the world.

2 The Universality of Concept Mapping

We know of no domain of knowledge where concept mapping cannot be applied, and continue to find new applications for the tool. In addition to the early use for assessing growth in conceptual understanding and helping students learn meaningfully, numerous other applications have appeared in the last 30 years, and it is likely that additional useful applications will be found for this tool in the future. We sketch below examples of some of the newer applications for the concept map tool.

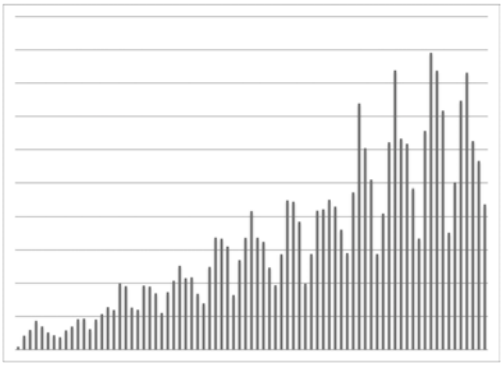

Figure 2. Monthly downloads for CmapTools show peaks when classes begin in the Northern and Southern Hemisphere, and valleys when schools and universities are on vacation

2.1 Facilitating Meaningful Learning

Given its roots described above, it is not surprising that the most prevalent application of concept mapping is in facilitating meaningful learning. Figure 2 shows a graph of the number of downloads of CmapTools from the IHMC download Website (there are other means of obtaining the

software which we have been encouraging lately, so this doesn't show the total number of users). In addition to showing the growth in number of downloads throughout the years, the graph also clearly depicts the peaks in downloads during the months of February, March, August and September, when the school year begins in the Southern and Northern Hemispheres, and valleys when most schools and universities are on vacation (July and December). Clearly education seems to continue to be the main application of concept mapping.

In the Epigraph to his 1968 and 1978 books, Ausubel (1968; 1978) states:

> *If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows, Ascertain this and teach him accordingly.*

Simple as this may appear, it is profoundly difficult to ascertain *precisely* what a person already knows. In fact, it was this problem that led us to the development of the concept map tool, as noted above. While it is difficult to assess what an individual knows about a given topic or problem, it is even more difficult to assess precisely what a study team or group knows. Here again we have found concept maps to be an expedient and effective tool. We have also found it very important to define carefully the problem or issue to be addressed and to construct carefully a "focus question" to guide the knowledge elicitation process. There is an iterative process between designing a focus question, soliciting or searching for relevant knowledge, concept mapping that knowledge, and then perhaps refining the focus question or asking more questions (Cañas & Novak, 2006b; Chacón, 2006) that has proven to be very effective. This iterative process, supported with the tools provided by CmapTools such as collaboration and searching for information relative to a concept map, has lead to the concept-map based learning environment's New Model of Education (Novak & Cañas, 2004). When concept maps are used as pretests and then employed with new learning materials, research has shown that meaningful learning can be much facilitated (Al-Kunifred & Wandersee, 1990; Novak & Gowin, 1984; Novak & Wandersee, 1990).

The use of concept maps within education varies widely, from schools which have adopted our ideas and use concept maps and CmapTools in all subjects and grades with extraordinary results like the Instituto de Educación Integral in Costa Rica (Silesky & Badilla, 2008), to efforts to introduce concept mapping into public schools at a country-wide level (Tarté, 2006) or having CmapTools installed in all computers delivered to schools for a whole region (Garcia, 2010), but unfortunately also includes teachers that give the students pre-built concept maps to memorize, or partially filled concept maps to "fill-in-the-blanks". Overall, we have found that there is room for improvement to take advantage of concept mapping's full potential (Cañas & Novak, 2006b). However, it is clear that concept maps are useful, and are being used, from pre-school to graduate school, research groups, corporate learning and lifelong learning, and in any subject matter area. As examples we proceed to present some uses and subject areas, without any intention of being complete or extensive, as most of the application in schools and universities is not reported in the literature. References are samples of use, not comprehensive reports on each area.

Concept mapping has been shown to be effective when used as an assessment tool (Fischler, et al., 2002; McGaghie, McCrimmon, Thompson, Ravitch, & Mitchell, 2000; Reiska, 2005; West, Pomeroy, Park, Gerstenberger, & Sandoval, 2000) at all levels of education. When used with pre-school or elementary school children, they also facilitate language learning and learning to read as well better ways to learn (Beirute, Brenes, Cortés, García, & Meza, 2006; Cassata-Widera, 2009; Mancinelli, 2006). Elementary (primary) education is probably the educational level where concept mapping is most popular and has received more attention in terms of its effectiveness, with less reports found on use at the secondary/high school level. At all educational levels, science seems to be the subject where concept mapping is applied the most (Heinze-Fry, 2004; Novak & Wandersee, 1990). Concept mapping has been used less in mathematics, but within the last few years we have seen an increase it its use as reported in Afamasaga-Fuata'i (2009). Additionally, concept mapping has been applied to reading comprehension (Conlon, 2008; Iraizoz Sanzol & González, 2003) writing (Straubel, 2006), learning foreign languages (Bahr & Dansereau, 2001; Marriott & Torres, 2008), as well as social studies (Chatterjea, 2008; Trygestad, 1997). At the college level, concept mapping is used in a large variety or programs, including engineering (Darmofal, 2002; Walker & King, 2002), nursing (Daley, 1996), biology (Henno & Reiska, 2008; Kinchin, 2000; Trifone, 2006), chemistry (Shanze & Grüß-Niehaus, 2008), physics (Pérez, Suero, Montanero, & Pardo, 2004), medicine (Brüchner & Sascha Schanze, 2004; Daley, et al., 2006), veterinary (Edmondson & Smith, 1996), psychology (Carnot & Stewart, 2006), vocational education (Reiska & Ruohotie, 2008), business schools (Leauby & Brazina, 1998; Simon, 2007) and of course Schools of Education (Himangshu, Iuli, & Venn, 2008) among others, and we have seen large collections of concept maps used in the learning of physical education, sports and music and art. Additionally,

concept mapping facilitates the integration of different curriculum subjects. At the graduate level, success is reported in the use of concept mapping within research programs (Markham, Mintzes, & Jones, 1994; Okada, 2008; Wallace & Mintzes, 1990). Training programs at organizations and corporations have also benefited from the use of concept mapping (Bowen & Meyer, 2008; Trujillo, 2008).

Concept mapping is also used within the education community for curriculum development (Edmondson, 1995; Heinze-Fry & Ludwig, 2006; Riesco, Fondón, & Álvarez, 2008). Across ages and subjects, concept mapping has been proven to be an effective tool to engage students in collaboration and collaborative projects (Basque & Lavoie, 2006; Tifi & Lombardi, 2006; Torres & Marriott, 2010) as well as for distance learning (Dutra, Fagundes, & Cañas, 2004) and organizing learning content (Kumar & Saigal, 2005). Concept mapping has been used with dyslexic students (Lami & Locatelli, 2008), students with hearing impairments (Peña, Bernal, & López, 2008), blind students (Sánchez & Flores, 2010) and autistic children (Roberts & Joiner, 2007). Additionally, we have seen concept maps created by home-schoolers in the IHMC CmapServers. For lack of space we won't go into the numerous activities in the classroom that can be supported through concept mapping.

It is clear that concept mapping has had a large impact on students, teachers, and educational systems all over the world.

2.2 Knowledge Management

Much of the funding at the Institute for Human and Machine Cognition (IHMC) for the development of CmapTools came from US federal agencies who saw value in the use of concept maps to capture and archive expert knowledge in a form that would be easy to use by others. In a sense, eliciting the knowledge from an expert and representing it in such a way that its easily understood is not much different from assessing the knowledge of a school-age student. Thus, the same tools and software are used to graphically express the knowledge of elementary school children and of world-class experts.

These efforts have resulted in several projects, both at IHMC and by others, that show the feasibility of using concept maps to capture and archive knowledge. The first such effort was NUCES (Ford, Coffey, Cañas, Andrews, & Turner, 1996), an expert system to aid in the diagnosis of heart diseases. Other such systems, based on knowledge engineers interviewing experts (Coffey & Hoffman, 2003) include El-Tech, which demonstrated the approach was feasible with Navy technicians (Coffey, et al., 2003), STORM-LK, which modeled weather forecasting in the Gulf of Mexico (Hoffman, Coffey, Ford, & Novak, 2006), and projects with power plant engineers (Coffey, Eskridge, & Sanchez, 2004), among others. Concept mapping as a tool for knowledge elicitation has since been used by other organizations, including the Electrical Power Research Institute (EPRI, 2007; Hanes & Ziebell, 2004). Barbara Bowen of Sound Knowledge Strategies reports on the use of concept maps for team knowledge elicitation at public health agency (Bowen, 2010) and Preciado et al. (2008) report on the use in the design of a competitiveness system. Beyond knowledge elicitation, concept mapping's use in organization has spread within other areas of knowledge management, as reported by Henao et al. (2007) and Basque et al. (2004). Its important to note that eliciting knowledge is not limited to professional or science experts. At the request of the Queen of Thailand, Hoffman and his colleagues at IHMC prepared a prototype Knowledge Model dealing with Thai fabric design and creation. Thailand has a long history of leadership in this area, many of its craftsmen are reaching old age, and the Queen wanted to preserve this knowledge.

2.3 Other Business Applications

Beyond Knowledge Management, corporations and organizations worldwide are using concept mapping. Unfortunately most of them are reluctant to share their experience and so reports of their use come from the academic community or through informal communications. For example, Fourie & Westhuizen (2008) write on the use of concept mapping for strategic alignment, Kyrö & Niskanen (2008) on the use in business planning, and Dumestre (2004) on performing job task analysis. Concept mapping has been known to be used for requirements elicitation and specification (Freeman, 2004) both during the development of computer system and for the requisition and purchasing. This application is in line with the use reported by consultants where they use concept maps as a means to agree with their customers on statements of work.

Concept maps have been reported to be used for project management, including project proposals and project reports (Ramírez, Flores, & Barros, 2008). At IHMC we use concept mapping as a tool for capturing the results of Blue Sky-type brainstorm and innovation meetings and as means to prepare the resulting reports, and we are aware of their use for brainstorming and minute-taking at meetings in many organizations. In a similar application, concept maps have been used to document software development and products.

Intelligence organizations in several countries use concept mapping as a tool in social networking, to keep track of relationships between individuals, their locations, actions, contacts, etc. Unfortunately this use is classified. An analogous use is that of investigative reporting by journalists, where concept mapping is used to track the information about a case being investigated, keeping all journalists up-to-date, and for detecting missing links in the information.

Other business applications have included the combination of concept maps or CmapTools with other software as part of a larger system. Typical of this application is the use of concept maps as part of ontology or thesaurus generation, where concept maps are used as a friendlier interface for users than the formal representation of an ontology. Another such application is the combination of CmapTools with proprietary software developed by MedTrack to provide Electronic Medical Records (EMR) that contain essential information for a given patient that are complete and cover all aspects of the patient's medical history and aftercare instructions (Helfgott, Brewer, Novak, & Schanhals, 2010). Business applications of concept mapping are more prevalent than what the literature tends to show. Moon et al. (to appear, 2010) contains additional applications of concept maps in organizations and businesses.

2.4 Organizing & Navigating through Information

Concept maps have been known to be an effective tool to organize and navigate through large volumes of information (Carnot, Dunn, Cañas, Graham, & Muldoon, 2001), and there are quite a few sites that use them for this purpose. Perhaps the most extensive of such efforts was work done by Geoff Briggs at NASA Ames Research Center to create an extensive knowledge model consisting of over 300 concept maps dealing with Mars and Mars exploration (Briggs, et al., 2004), and which has extended to the rest of the Solar System. With a similar purpose, concept maps have been used as a tool to design Websites.

Beirute & Mayorga (2004) have used concept mapping for conflict resolution, and Fraser (1993) found that concept maps prepared by workers in computer sales, when shared between workers who had conflicts, quickly resolved the conflicts, and this improvement in cooperation continued. This list of applications is by no means exhaustive. There are personal uses of concept maps, such as planning a vacation, which we run into all the time through personal communications or just by browsing through the CmapServers, as well as other educational, business, and corporate uses. We have no doubt of the universality of the application of concept mapping.

3 On the Ubiquitousness of Concept Maps

Kinchin (2001) has asked why aren't we all using concept mapping in the classroom, if they are so helpful. At the closing session in Helsinki at CMC2008, the Third International Conference on Concept Mapping, Tom Conlon questioned how many more papers we need to write showing positive results of the use of concept mapping in different educational settings before we see a broader use of the tool in schools, and proposed that we ask ourselves what needs to change (in the tool? in existing software?) before concept mapping is used more extensively.

We would like to broaden these questions to concept mapping in general. If concept maps are applicable to so many domains and are used by people of all ages, why is it that we don't "run into" concept maps more often? We could argue that at any point in time, somebody somewhere in the world is busy constructing a concept map.[2] The index of searchable concept maps at www.Cmappers.net is up to around 400,000 maps that have been made public. Although this seems like a large number, it's actually small compared to the total number of concept maps being built using CmapTools. Browsing through these Cmaps shows that many of them are "test" maps, and a good portion are maps constructed during workshops, practice maps, many of them incomplete. And although there are a

[2] Based on the logs of public CmapServers at IHMC, where we can observe the rate at which Cmaps are being saved using CmapTools.

large number of well constructed, relevant, and interesting Cmaps, there should be more of them.[3] Apparently we keep our good Cmaps to ourselves. Its understandable that a number of Cmaps within corporations need to be kept private, but given the number of concept mappers worldwide, its likely there are a lot of good concept maps that are not being shared and could be of use to others.

We should be seeing concept maps as explanations (illustrations) in books, papers, reports, proposals, presentations, Websites, and all types of documents. However, we seldom find concept maps as explanations in documents, we mostly find concept maps as examples in papers about concept mapping; and even within these papers we don't find concept maps as summaries or explanations of the paper itself. If we believe concept maps are good for communicating ideas, why don't we see more concept map-based presentations at the Concept Mapping Conferences?

When textbooks make reference to concept mapping, they mostly provide exercises consisting of a concept map with some blank labels for some concepts for students to fill-in the blanks, which is probably one of the worse uses of concept maps in the classroom.[4] Textbook exercises don't use concept maps as a means of integrating content, building on a set of concept maps as the student progresses through the chapters.

It seems that Cmappers are not using concept maps for "communicating" or sharing their knowledge. There may be several reasons for this. First, people may not be very secure about their concept maps, and even though they may be building them when preparing documents, reports, etc., they prefer not to include them in their final work. Second, users may use concept mapping as a way to organize their thoughts but never "finalize" their concept maps to the point where they can be published. Third, the technology available may not be flexible enough to make the concept maps more ubiquitous. Even though software like CmapTools make it easy to export Cmaps as images, PDFs, or Web pages, and to publish them on the Web, the integration into popular software packages like Microsoft Office, Wikis, Blogs, Facebook and Moodle might increase their visibility. Last, constructing concept maps is not easy – it requires effort to build a good map, which may lead to users opting not to build concept maps because of the time required.

As an initial step, we propose that the papers submitted to future Concept Mapping Conferences should include a concept map instead of a text Abstract. We have begun by including a Cmap in lieu of an Abstract in this paper. We encourage the Cmappers community to be more forthcoming in the use of concept maps. The universality of the application provides numerous opportunities to use the concept maps, and showing the use of the tool through good concept maps is a way of educating the general public on its use.

4 Summary

The examples given above illustrate some of the broad range of activities related to learning, creating, and using knowledge for which concept maps can serve a useful, productive, and facilitative role (Novak, 1998, 2010). Over the years it has been demonstrated that concept maps can be used from pre-school to research laboratories and corporations for any subject matter. Each year we see new applications of this tool and new possibilities that need to be explored. Bush (1945) characterized science as an endless frontier. We see applications for the concept map tool as also an endless frontier.

Regarding the lack of ubiquitousness of concept maps, one could see the current status as encouraging or discouraging. Considering the humble beginnings for the use of this tool to monitor changes in children's understanding of basic science concepts to the many application we report here, one could conclude that great progress has been made. However, when one looks at all the human activities that deal with knowledge that could benefit from the use of this tool, the percentage of the world population employing the tools is small. There is much work to be done to "spread the word" and we invite all readers to join in this effort.

[3] The Cmappers search only retrieves Cmaps with a high topological taxonomy value, assuming these maps will be of higher interest.
[4] When Cañas met with a textbook publisher to explain why these type of exercises were not recommended, the publisher indicated they understood. Instead of changing the exercises they changed the term "concept map" for "map" and the exercises appeared in the next printing.

5 References

Afamasaga-Fuata'i, K. (Ed.). (2009). *Concept Mapping in Mathematics*: Springer.

Al-Kunifred, A., & Wandersee, J. (1990). One hundred references related to concept mapping. *Journal of Research in Science Teaching, 27*(10), 1069-1075.

Ausubel, D. P. (1963). *The Psychology of Meaningful Verbal Learning*. New York: Grune and Stratton.

Ausubel, D. P. (1968). *Educational Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston.

Ausubel, D. P., Novak, J. D., & Hanesian, H. (1978). *Educational Psychology: A Cognitive View* (2nd ed.). New York: Holt, Rinehart and Winston.

Bahr, S., & Dansereau, D. (2001). Bilingual Knowledge Maps (BiK-Maps) in Second Language Vocabulary Learning. *Journal of Experimental Education, 70*(1), 5-24.

Basque, J., Imbeault, C., Pudelko, B., & Léonard, M. (2004). Collaborative Knowledge Modeling between Experts and Novices: A Strategy to Support Transfer of Expertise in an Organizations. In A. J. Cañas, J. D. Novak & F. F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proc. of the First Int. Conference on Concept Mapping*. Pamplona, Spain: Universidad Pública de Navarra.

Basque, J., & Lavoie, M.-C. (2006). Collaborative Concept Mapping in Education: Major Research Issues. In A. J. Cañas & J. D. NOvak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. I). San José, Costa Rica: Universidad de Costa Rica.

Beirute, L., Brenes, M., Cortés, G., García, S., & Meza, A. (2006). La Contrucción de Mapas Conceptuales en Edad Preescolar. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. 2, pp. 143-146). San Jose, Costa Rica: Universidad de Costa Rica.

Beirute, L., & Mayorga, L. F. (2004). Los Mapas Conceptuales Herramienta Poderosa en la Resolución Alternativa de Conflictos. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the 1st International Conference on Concept Mapping* (Vol. I). Pamplona, Spain: Universidad Pública de Navarra.

Bowen, B. L. (2010). Using Concept Map-based Team Knowledge Elicitation to Enhance Organizational Effectiveness for a Public Health Agency. In J. Sánchez, A. J. Cañas & J. D. Novak (Eds.), *Proc. of the 4th Int. Conference on Concept Mapping*. Viña del Mar, Chile: Universidad de Chile.

Bowen, B. L., & Meyer, M. M. (2008). Applying Novak's New Model of Education to Facilitate Organizational Effectiveness, Professional Development and Capacity-Building for the New Teacher Allience. In A. J. Cañas, P. Reiska, M. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Ind. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

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

Brüchner, K., & Sascha Schanze. (2004). *Using Concept Maps for Individual Knowledge Externalization in Medical Education*. Paper presented at the Concept Maps. Theory, Methodology, Technology. Proc. of the First Int. Conference on Concept Mapping.

Bush, V. (1945). *Science The Endless Frontier*. Washington DC: US Government Printing Office.

Cañas, A. J., Carff, R., Hill, G., Carvalho, M., Arguedas, M., Eskridge, T., et al. (2005). Concept Maps: Integrating Knowledge and Information Visualization. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization: Searching for Synergies* (pp. 205-219). Heidelberg/NY: Springer Lecture Notes in Computer Science.

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

Cañas, A. J., & Novak, J. D. (2006a). *Concept Maps: Theory, Methodology, Technology. Second International Conference on Concept Mapping*. San José, Costa Rica: Editorial Universidad de Costa Rica.

Cañas, A. J., & Novak, J. D. (2006b). Re-Examining The Foundations for Effective Use of Concept Maps. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. 1, pp. 494-502). San Jose, Costa Rica: Universidad de Costa Rica.

Cañas, A. J., Novak, J. D., & González, F. (2004). *Concept Maps: Theory, Methodology, Technology. First International Conference on Concept Mapping*. Pamplona, Spain: Universidad Pública de Navarra.

Cañas, A. J., Reiska, P., Åhlberg, M. K., & Novak, J. D. (2008). *Concept Mapping: Connecting Educators. Third International Conference on Concept Mapping*. Tallinn, Estonia: Tallinn University.

Carnot, M. J., Dunn, B., Cañas, A. J., Graham, P., & Muldoon, J. (2001). Concept Maps vs. Web Pages for Information Searching and Browsing. from http://www.ihmc.us/users/acanas/Publications/CMapsVSWebPagesExp1/CMapsVSWebPagesExp1.htm

Carnot, M. J., & Stewart, D. (2006). Using Concept Maps in College Level Psychology and Social Work Classes. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Metodology, Technology. Proc. of the 2nd Int. Conference on Concept Mapping* (Vol. 2). San José, Costa Rica: Universidad de Costa Rica.

Cassata-Widera, A. (2009). *Concept Mapping with Young Children. From Representation to Metacognition*: VDN Verlag.

Chacón, S. (2006). La Pregunta Pedagógica Instrumento de Mediación en la Elaboración de Mapas Conceptuales. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping*. San José, Costa Rica: Universidad de Costa Rica.

Chatterjea, K. (2008). Using CmapTools for Integration of Concepts and a Holistic Geographic Understanding. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*. Tallinn, Estonia & Helsinki, FInland: Tallinn University.

Coffey, J. W., Cañas, A. J., Reichherzer, T., Hill, G. A., Suri, N., Carff, R., et al. (2003). Knowledge Modeling and the Creation of El-Tech: A Performance Support System for Electronic Technicians. *Expert Systems with Applications, 25*(4), 483-492.

Coffey, J. W., Eskridge, T. C., & Sanchez, D. P. (2004). A Case Study in Knowledge Elicitation for Institutional Memory Preservation using Concept Maps. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. 1). Pamplona, Spain: Universidad Pública de Navarra.

Coffey, J. W., & Hoffman, R. R. (2003). Knowledge Modeling for the Preservation of Institutional Memory. *Journal of Knowledge Management, 7*(3), 38-52.

Conlon, T. (2008). Practical Text Concept Mapping: New Pedagogy, New Technology. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Daley, B. J. (1996). Concept Maps: Linking Nursing Theory to Clinical Nursing Practice. *The Journal of Continuing Education in Nursing, 27*, 17-27.

Daley, B. J., Torre, D., Stark-Schweitzer, T., Siddartha, S., Ziebert, M., & Petkova, J. (2006). Advancing Teaching and Learning in Medical Education through the Use of Concept Maps. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology* (Vol. 1). San José, Costa Rica: Universidad de Costa Rica.

Darmofal, D. L. (2002). *Using Concept Maps and Concept Questions to Enhance Conceptual Understanding*.

Dumestre, J. C. (2004). Using CmapTools Software to Assist in Performing Job Task Analysis. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping*. Pamplona: Universidad Pública de Navarra.

Dutra, I., Fagundes, L., & Cañas, A. J. (2004). Un Enfoque Constructivista para Uso de Mapas Conceptuales en Educación a Distancia de Profesores. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping*. Pamplona: Universidad Pública de Navarra.

Edmondson, K. M. (1995). Concept Mapping for the Development of Medical Curricula. *Journal of Research in Science Teaching, 32*(7), 777-793.

Edmondson, K. M., & Smith, D. F. (1996). *Concept Mapping To Facilitate Veterinary Students' Understanding of Fluid and Electrolyte Disorders.* Paper presented at the American Educational Research Association.

EPRI. (2007). Expert Knowledge Capture and Transfer. Retrieved 2010, August 18, from http://mydocs.epri.com/docs/public/000000000001014853.pdf

Fischler, H., Peuckert, J., Dahncke, H., Behrendt, H., Reiska, P., Pushkin, D., et al. (2002). Concept Mapping as a Tool for Research in Science Education. In H. Behrendt, H. Dahncke, R. Duit, W. Gräber, M. Komorek, A. Kross & P. Reiska (Eds.), *Research in Science Education - Past, Present, and Future* (pp. 217-224): Springer Netherlands.

Ford, K. M., Coffey, J. W., Cañas, A. J., Andrews, E. J., & Turner, C. W. (1996). Diagnosis and Explanation by a Nuclear Cardiology Expert System. *International Journal of Expert Systems, 9*, 499-506.

Fourie, L. C. H., & Westhuizen, T. v. d. (2008). The Vallue and Use of Concept Maps in the Alignment of Strategic Intent. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Fraser, K. (1993). *Theory Based Use of Concept Mapping in Organizational Development: Creating Shared Understanding as a Basis for the Cooperative Design of Work Changes and Changes in Working Relationships.* Unpublished Ph.D. Dissertation, Cornell University, Ithaca, NY.

Freeman, L. A. (2004). The Effects of Concept Maps on Requirement Elicitation and System Models during Information Systems Development. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proc. of the First Int. Conference on Concept Mapping*. Pamplona, Spain: Universidad Pública de Navarra.

Garcia, E. P. (2010, August 18). CmapTools, en los ordenadores Escuela 2.0 en les Illes Balears. http://cosasdemapasconceptuales.blogspot.com/2010/01/cmaptools-en-los-ordenadores-escuela-20.html

Hanes, L., & Ziebell, D. (2004). *Real-Time Expert Knowledge Acquisition and Transfer – Needs and Technology Assessment: Toward Self-Elicitation and Automated Knowledge Capture Methods*. Palo Alto, CA: EPRI.

Heinze-Fry, J. (2004). Application of Concept Mapping to Undergraduate General Education Science Courses. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology* (Vol. 1). Pamplona, Spain: Universidad Pública de Navarra.

Heinze-Fry, J., & Ludwig, F. (2006). CmapTools Facilitates Alignment of Local Curriculum with State Standards: A Case Study. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. I). San José, Costa Rica: Universidad de Costa Rica.

Helfgott, M. A., Brewer, A., Novak, J. D., & Schanhals, R. (2010). Integrating Cmaps into the EMR: Using Concept Maps to Improve the Quality and Productivity in Clinical Documentation Systems Implementation and Maintenance. In J. Sánchez,

A. J. Cañas & J. D. Novak (Eds.), *Proc. of the Fourth Int. Conference on Concept Mapping*. VIña del Mar, Chile: Universidad de Chile.

Henao, C., Monica, Pia, A.-F., & Maria, G. (2007). Concept maps as a strategy to convert knowledge in knowledge management (Vol. 37, pp. 8). Bradford, ROYAUME-UNI: Emerald.

Henno, I., & Reiska, P. (2008). Using Concept Mapping as Assessment Tool in School Biology. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Himangshu, S., Iuli, R. J., & Venn, M. (2008). Impact Concept Mapping has on Pre-Service Teachers Understanding of Science Content Knowledge and Development of their Science Pedagogy. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Hoffman, R. R., Coffey, J. W., Ford, K. M., & Novak, J. D. (2006). A Method for Eliciting, Preserving, and Sharing the Knowledge of Forecasters. *Weather and Forecasting, 21*, 416-428.

Iraizoz Sanzol, N., & González, F. M. (2003). *El Mapa Conceptual: Un Instrumento Apropiado para Comprender Textos Expositivos*. Pamplona, España: Gobierno de Navarra.

Kinchin, I. M. (2000). Concept Mapping in Biology. *Journal of Biological Education, 34*(2), 61-68.

Kinchin, I. M. (2001). If Concept Mapping is So Helpful to Learning Biology, Why aren't We All Doing It? *International Journal of Science Education, 23*(12), 1257 - 1269.

Kumar, A., & Saigal, R. (2005). *Visual Understanding Environment.* Paper presented at the Proceedings of the 5th ACM/IEEE-CS Joint Conference on Digital Libraries, Denver, Colorado.

Kyrö, P., & Niskanen, V. A. (2008). A Concept Map Modeling Approach to Business Planning in a Computer Environment. In A. J. Cañas, P. Rieska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Lami, G., & Locatelli, M. (2008). Dyslexia and Concept Maps: An Indispensable tool for Learning. In A. J. Cañas, P. Reiska, M. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Leauby, B. A., & Brazina, P. (1998). Concept Mapping: Potential Uses in Accounting Education. *Journal of Accounting Education, 16*(1), 123-138.

Mancinelli, C. (2006). Learning While Having Fun: Conceptualization Itineraries in Kindergarten Children Experiences with C-Maps in an Italian School. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. 1, pp. 343-350). San Jose, Costa Rica: Universidad de Costa Rica.

Markham, K., Mintzes, J., & Jones, G. (1994). The concept map as a research and evaluation tool: Further evidence of validity. *Journal of Research in Science Teaching, 31*(1), 91-101.

Marriott, R. C. V., & Torres, P. L. (2008). Enhancing Collaborative and Meaningful Language Learning through Concept Mapping. In T. Sherborne, S. J. Buckingham Shum & A. Okada (Eds.), *Knowledge Cartography* (pp. 47-72): Springer London.

McGaghie, W. C., McCrimmon, D. R., Thompson, J. A., Ravitch, M. M., & Mitchell, G. (2000). Medical and Veterinary Students' Structural Knowledge of Pulmonary Physiology Concepts. *Academic Medicine, 75*(4), 362-368.

Moon, B., Hoffman, R., Novak, J. D., & Cañas, A. J. (to appear, 2010). *Applied Concept Mapping: Capturing, Analyzing and Organizing Knowledge*: Productivity Press, Taylor & Francis.

Novak, J. D. (1972). The Use of Audio-Tutorial Methods in Elementary School Instruction. In S. N. Postlethwait, J. D. Novak & H. F. Murray (Eds.), *The Audio-Tutorial Approach to Learning* (pp. 110-120). Minneapolis, MN: Burgess.

Novak, J. D. (1993). Human Constructivism: A Unification of Psychological and Epistemological Phenomena in Meaning Making. *International Journal of Personal Construct Psychology, 6*, 167-193.

Novak, J. D. (1998). *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. Mahwah, NJ: Lawrence Erlbaum Associates.

Novak, J. D. (2010). *Learning, Creating and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations* (2nd ed.). New York: Routledge.

Novak, J. D., & Cañas, A. J. (2004). Building on Constructivist Ideas and CmapTools to Create a New Model for Education. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the 1st International Conference on Concept Mapping*. Pamplona, Spain: Universidad Pública de Navarra.

Novak, J. D., & Cañas, A. J. (2006). The Origins of the Concept Mapping Tool and the Continuing Evolution of the Tool. *Information Visualization Journal, 5*(3), 175-184.

Novak, J. D., & Gowin, D. B. (1984). *Learning How to Learn*. New York, NY: Cambridge University Press.

Novak, J. D., & Wandersee, J. (Eds.). (1990). *Journal of Research in Science Teaching: Special Issue: Perspectives on Concept Mapping* (Vol. 27(10)).

Okada, A. (2008). Mapping Knowledge to Develop Academic Research in Collaborative Learning Environments. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Peña, E., Bernal, D., & López, D. (2008). Concept Maps: A Tool to Improve Reading Comprehension Skills of Children with Hearing Impairments. In A. J. Cañas, P. Reiska, M. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Pérez, Á. L., Suero, M. I., Montanero, M., & Pardo, P. J. (2004). Aplicaciones de la Teoría de la Elaboración de Reigeluth y Stein a la Enseñanza de la Física. Una Propuesta Basada en la Utilización del Programa Informático CmapTools. In A. J. Cañas, J. D. Novak & F. M. González (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping* (Vol. I). Pamplona: Universidad Pública de Navarra.

Preciado, D. J. S., Gallo, L. S. P., & Tenorio, A. L. P. (2008). *The Concept Map as a Tool for Designing a Competitiveness and Innovation System for Cauca - Colombia*. Paper presented at the Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping.

Ramírez, C., Flores, W., & Barros, R. (2008). Concept Maps: A Strategy for the Development of Technical Reports on Industrial Engineering Problems. In M. K. Åhlberg (Ed.), *Concept Mapping: Connecting Educators*. Tallin, Estonia & Helsinki, Finland: Tallinn University.

Reiska, P. (2005). *Experimente and Computersimulationen. Empirische Untersuchung zum Handeln im Experiment und am Computer unter dem Einfluss von physikalischem Wissen.* Frankfurt a. M.: Peter Lang.

Reiska, P., & Ruohotie, P. (2008). Using Concept Mapping in Vocational Education. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Riesco, M., Fondón, M. D., & Álvarez, D. (2008). Designing Degrees: Generating Concepts Maps for the Description of Relationships between Subjects. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Roberts, V., & Joiner, R. (2007). Investigating the Efficacy of Concept Mapping with Pupils with Autistic Spectrum Disorder. *British Journal of Special Education, 34*(3), 127-135.

Sánchez, J., & Flores, H. (2010). Concept Mapping for Virtual Rehabilitation and Training of the Blind. *IEEE Trans. on Neural Systems and Rehabilitation Engineering, 18*(2), 210-219.

Shanze, S., & Grüß-Niehaus, T. (2008). Supporting Comprehension in Chemistry Education - The Effect of Computer Generated and Progressive Concept Mapping. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the Third Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: University of Tallinn.

Silesky, O., & Badilla, E. (2008). A Map Towards Innovation in Education. *Keynote Presentation at the 3rd International Conference on Concept Mapping* Retrieved November 11, 2008, from http://cmapspublic3.ihmc.us/rid=1FHGJHRNH-1L2DD57-1XP3/Innovation%20in%20Education.cmap

Simon, J. (2007). Concept Mapping in a Financial Accounting Theory Course. *Accounting Education: An International Journal, 16*(3), 273-308.

Straubel, L. H. (2006). Character and Plot Nodes: Writing Fiction with Concept Maps. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proc. of the 2nd Int. Conference on Concept Mapping*. San José, Costa Rica: Universidad de Costa Rica.

Tarté, G. (2006). Conéctate al Conocimiento: Una Estrategia Nacional de Panamá basada en Mapas Conceptuales. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. 1, pp. 144-152). San José, Costa Rica: Universidad de Costa Rica.

Tifi, A., & Lombardi, A. (2006). WWMaps, A Community on Education Through Collaborative Concept Mapping. In A. J. Cañas & J. D. Novak (Eds.), *Concept Maps: Theory, Methodology, Technology. Proceedings of the Second International Conference on Concept Mapping* (Vol. 1). San José, Costa Rica: Universidad de Costa Rica.

Torres, P. L., & Marriott, R. d. C. V. (Eds.). (2010). *Handbook of Research on Collaborative Learning using Concept Mapping*. PA: Information Science Reference.

Trifone, J. D. (2006). To What Extent can Concept Mapping Motivate Students to Take a More Meaningful Approach to Learning Biology? *The Science Education Review, 5*(4), 122:121-122:123.

Trujillo, F. (2008). The Value Proposition - The InG.Bs1.val Model based on the Blue Ocean Strategy. In A. J. Cañas, P. Reiska, M. K. Åhlberg & J. D. Novak (Eds.), *Concept Mapping: Connecting Educators. Proc. of the 3rd Int. Conference on Concept Mapping*. Tallinn, Estonia & Helsinki, Finland: Tallinn University.

Trygestad, J. (1997). *Students' Conceptual Thinking in Geography.*

Walker, J. M. T., & King, P. H. (2002). *Concept Mapping as a Form of Student Assessment and Instruction*. Paper presented at the Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.

Wallace, J., & Mintzes, J. (1990). The concept map as a research tool: Exploring conceptual change in biology. *Journal of Research in Science Teaching, 27*(10), 1033-1052.

West, D., Pomeroy, J. R., Park, J., Gerstenberger, E., & Sandoval, J. (2000). Critical thinking in graduate medical education. *Journal of the American Medical Association, 284*(9), 1105-1110.