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ADVANCING CONCEPT MAP RESEARCH: A REVIEW OF 2004 AND 2006 CMC RESEARCH

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Abstract. The purpose of this study was to conduct an integrative literature review of all papers and posters presented at the 2004 and 2006 Concept Mapping Conferences. In this review, 322 papers and posters, written in both English and Spanish, were reviewed. Six researchers reviewed the papers and created a matrix outlining each research study, the methods, the findings, and the implications. This matrix was then used to conduct a meta-analysis and identify six overall themes of research presented at the 2004 and 2006. These themes were identified as 1. teaching and learning, 2. assessment and scoring, 3. knowledge development, 4. software development, 5. professional development, and 6. research methods. In addition, researchers propose directions for future research in concept mapping.

1 Introduction

Concept maps were originally created at Cornell University as a research tool by Dr. Joseph Novak. Novak and his colleagues were conducting a 12 year longitudinal study on how children learn science concepts. In this study they created "28 lessons that dealt with the particulate nature of matter, energy types and energy transformations and energy utilization in living things" (Novak, 2004, p. 458). Children completed audio-tutorial lessons on these topics and then the research team interviewed these students about their learning. With hundreds of interview tapes to analyze, the research team began looking for alternative data analysis strategies. As Novak (2004) indicates, "in our discussions, the idea developed to translate interview transcripts into a hierarchical structure of concepts and relationships between concepts (i.e., propositions). The ideas developed into the invention of a tool we now call the "*concept map*" (p. 460). Novak and colleagues continued to research and teach with concept maps over the years and eventually initiated a partnership with the Institute for Human and Machine Cognition (IHMC). IHMC developed CmapTools, a software program for creating computer generated concept maps. Over the last few years, IHMC has continued the development of CmapTools and facilitated the creation of the International Concept Mapping Conference (CMC), with the first conference being held in Pamplona, Spain in 2004 and the second conference being held in San Jose, Costa Rica in 2006.

As we approach the third concept mapping conference, we believe it is time to step back and analyze the work that has been done to date and articulate some possible directions for future research in concept mapping. The use of concept maps has grown and developed in teaching and learning, in research, in business, and in working with small groups to name but a few examples. But how is all this research linked together? Are there future directions that research in concept mapping needs to explore? What can we learn from previous research that informs our practice and our future studies? In this paper we pose the overall question: Can the research agenda in concept mapping be advanced by conducting a meta-analysis of conference proceedings from the 2004 and 2006 conference? The purpose of this paper is to report the results of a meta-analysis of all papers and posters in the previous CMC proceedings.

2 Research questions

The following research questions were advanced to guide this inquiry: 1. What types of research have been conducted at the 2004 and 2006 CMC conferences? 2. What overall research themes are represented at the conferences? 3. How do these research themes advance knowledge in the area of concept mapping? 4. What implications do the research papers and themes have for future work in the area of concept mapping?

3 Methodology

According to Creswell (2008), a thematic integrative literature review is one in which the researcher uses the literature to identify themes and patterns in areas of research, and then discusses those themes with general reference to the studies from which they came. Drawing from the conference web site and published proceedings, three English speaking and three Spanish/ English speaking researchers conducted a thematic literature review of the entire set of conference papers and posters from the 2004 and 2006 CMC conferences. The researchers reviewed 322 papers and posters in English or Spanish, and were unable to review only one submission, which was in a language other than English or Spanish that was not spoken by the researchers, The papers reviewed were from 38 different countries. During this review each researcher contributed to a matrix

that specified the name of the paper, the authors, the language of the paper, the country(ies) of the researcher(s), the year of publication, a short summary of the article, the methods, the findings, and the implications for practice and research. From this matrix initial themes were identified that represented the major research categories and topics presented at the CMC conference. The researchers then met to discuss, refine, and modify the initial themes created and to agree on the final list of six themes. A concept map (Figure 1) was created identifying these major themes.

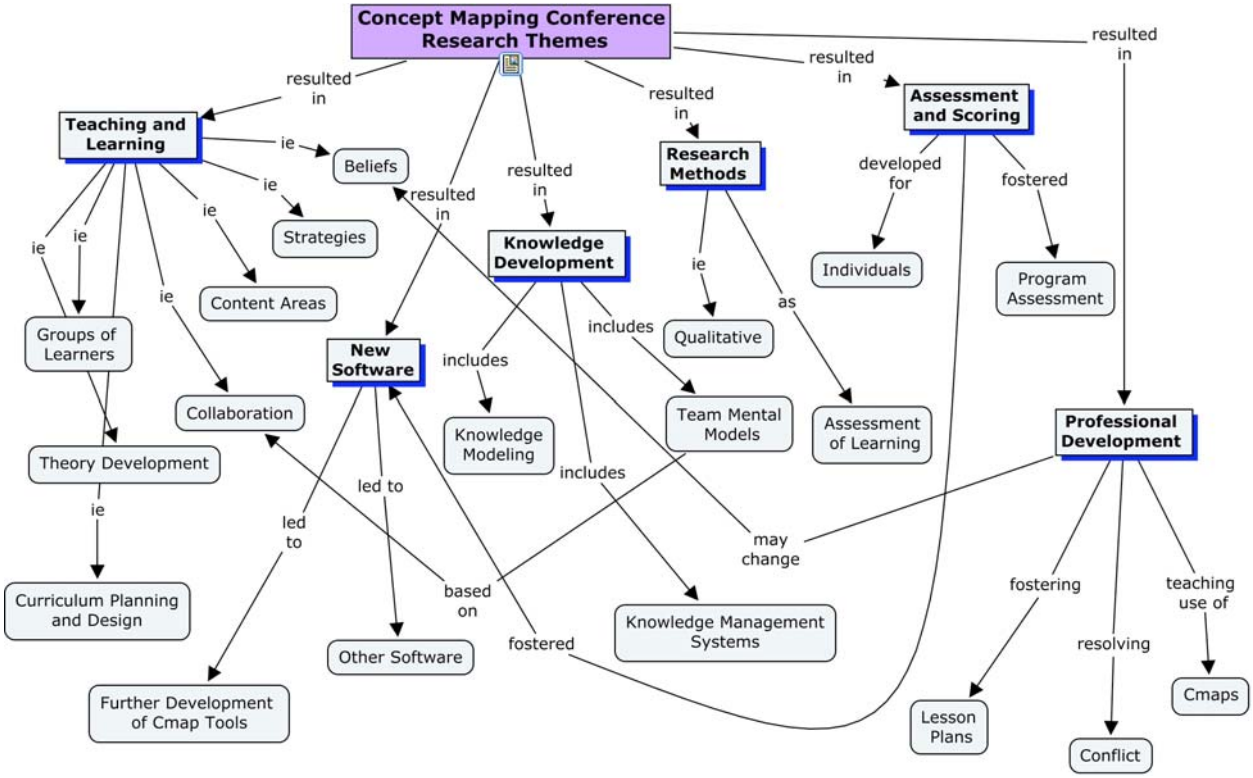

Figure 1: Concept Map of Research Themes Identified in CMC 2004/2006

4 Research themes identified

According to Mandl and Fischer (2000) there are currently "three major fields where concept mapping is used, namely as a teach-and-learn strategy tool, a cooperation process application, and as a tool for knowledge gathering, diagnosis and modeling" (as cited in Fourie & Schilawa, 2004, p.250). Based on our review of the CMC conference proceedings, it is evident that the use of concept maps has expanded into many other areas as well. As shown in Figure 1, we identified the following areas where concept mapping was being investigated in the CMC 2004 and 2006 conferences: teaching and learning, assessment and scoring, knowledge development, creation and expansion of software, research methods, and professional development. Each of these areas is discussed briefly in the next section of this paper.

4.1 Teaching and Learning

The theme that generated the largest number of papers was on the application of concept maps as a teaching and learning tool and the presentation of innovative ways of using concept maps. For student learning, concept maps have been used as advance organizers (Nathan & Kozminsky, 2004; Tavares, 2004), for educational group activities (Rojas-Drummond & Anzures, 2006), to produce a virtual magazine (Vargas, 2004), to improve reading and comprehension (Aránguiz, Berraondo, & Torre, 2004), to teach math (Edurne, Arantza, & Fermin, 2006; Olivares, 2006; Bolte, 2006), as a research tool (Åhlberg, 2004), as part of sharing teaching experiences (Ramos, 2004), as a self-reflection and self-regulation tool (Hugo & Chrobak, 2004), and to do research and complete literature reviews (Tysick, 2004).

4.1.1 Instructional Strategies

For instructors, concept maps have been used as a tool to organize instruction and to gather student feedback on learning (Fonseca, Extremina, & Fonseca, 2004), to assess student word problems through action research (Prabhu, Elmesky, & Czarnocha, 2006), to prepare teachers through portfolios and course planning (Iuli, Wagle, & Voetterl, 2006), and to assess understanding of science concepts and science language production (Stoddart, 2006). Papers also described innovative methods for using concept maps: pictorial concept maps (non-hierarchical and with limited linking words) to provide medication instructions for patients who have chronic diseases and low literacy (Hill, 2006), crossword puzzles and concept mapping (Tifi, 2004), construction of relevant terms for googling using a concept map and keywords generated from main concepts (Cañas, Carvalho, Arguedas, & Eskridge, 2004), and creation of maps with aluminum foil as the connections promoted creativity (Lombardi & Tifi, 2004).

4.1.2 Beliefs

A few conference papers focused on teacher beliefs. Mellado, Silva, and Ruiz (2004) wrote about their use of concept maps on interviews as instruments of analysis of high school science teachers' understandings about their own teaching. Banet, Sánchez, and Valcárcel (2004) used concept maps for analysis and reflection of university teaching in order to identify the teaching characteristics and to allow instructors to critically analyze their own teaching practice. González, Bermejo, and Mellado (2004) described a longitudinal study comparing a high school biology teacher's thinking about teaching and learning through a questionnaire and concept map analysis.

4.1.3 Content Areas

Papers focused on research on teaching and learning related to a variety of content areas. Some of the content areas included engineering (Feregrino-Hernández, Reza-García, Ortiz-Esquivel, Navarro-Clemente, & Domínguez-Pérez, 2006; Cálad, 2004), math (Heinze-Fry, 2004; Oneca, Sanzol, & Poveda, 2006; Vagliardo, 2004), physics (Alias & Tukiran, 2006; Valadares, Fonseca, & Soares, 2004); medical education (Illas, 2006), photography (Gimena, 2004), writing (Straubel, 2006), and pharmacy (Hill, 2006).

4.1.4 Groups of Learners

Papers were written based on the study of different groups of learners ranging from kindergarten (Mancinelli, 2006), elementary (Venditti & Sabba, 2006; Aquilino & Patrizia Venditti, 2006), middle, and high school learners (Pantò, Tifi, Trinchero, Vayola, & Zucchini, 2004), undergraduate and graduate students, medical students, and business learners (Bowen, 2006).

4.1.5 Theory Development

Some of the conference papers focused on theory development or analysis of existing theories in the use of concept maps and Vee diagrams. For example, Tamayo and Arroyo (2004) contended that concept maps are symbolic systems that represent a narrative and, therefore, can be interpreted. Tamayo (2004) states that reading a concept map is not only a representation of a text, but also the text itself with cultural and symbolic characteristics. In 2006, Tamayo presented a theoretical paper addressing the concept of immediate development zone by Novak as guiding the learning process and connecting concept maps within Vygotsky's social cultural theory. Several papers stressed the application of Reigeluth Elaboration Theory on the use of concept maps (Pérez, Suero, Montanero, & Pardo, 2004; Murillo, Zamora, Martínez, Alcalde, & Ballester, 2004; Solano, Pérez, & Suero, 2004; Pérez, Suero, Montanero, & Pardo, 2004). Kankkunen (2004) attempted to link Peirce's semiotic paradigm and concept mapping as a way to explain different levels of reasoning.

4.1.6 Collaboration

Collaboration has been a strong theme within the different papers for both conferences. Some papers suggested new methods for doing collaboration; others suggested new ways of looking at collaborations. Tifi and Lombardi (2006) described the WWMAPS, a community of education through collaborative concept mapping for primary and secondary schools across cultures to enhance multi-lingual skills. Lehmuskallio (2006) proposed a global information system called NatureGate which uses concept maps to explain ecological, economical, and social sustainable development. Khamesan and Hammond (2004) looked at synchronous collaborative concept mapping via text and text/audio enhancement with computers. Berionni and Baldón (2006) described how teachers in Italy launched an innovative project about community building across ages and cultures in science teaching with students 6-13 years old. Rodríguez, López; Fernández, and Montanero (2006) showed the process of collaborative reconstruction of concept maps with future physics teachers.

Gustavigna et al. (2004) described the development of a community of practice of concept mapping in Italy. The community aimed at structuring and organizing selective criteria in order to produce and make available documentation.

4.1.7 Curriculum Planning and Design

Concept maps have been utilized to plan and design curriculum using a variety of strategies. Vilela, Austrilino, and Costa (2004) used concept maps as a curriculum development tool by having a group of curriculum developers identify missing linkages, inconsistencies, false assumptions, and unrecognized relationships. Cantú, Farines, and Angotti (2004) described the use of concept maps to generate a thematic approach to organizing curricula. Colli, Rossi, Giordani, and Carla Montagna (2004) described methods instructors used to organize their curriculum using CmapTools to examine and explain ideas. Cabral, Zeve, Nicolao, and Amoretti (2004) described a method of using concept maps to organize web pages for distance learning courses. With the purpose of identifying major curricular issues in a graduate program in Turkey, Paykoç, Mengi, Kamay, Önkol, Özgür, Pilli, and Şahinkayası (2004) described the use of a mind mapping process to brainstorm key issues and to evaluate the program. Bueno and García (2004) utilized document analysis through concept maps to compare methods used to determine the profile of the curriculum in the area of science in secondary education. Riveros, Castro, and Gutiérrez (2006) used concept maps to formulate, update, plan, and follow-up on an engineering curriculum program.

4.2 Assessment and Scoring

The second theme identified in this literature review was assessment and scoring. Concept map research was being conducted on how to score the maps of individual learners and how to use maps in the assessment of programs.

Numerous authors discussed the development of formulas for scoring individual maps. Yao, Yang, and Zhao (2006), for example, proposed an algorithm based on scoring the propositional chains in concept maps. In this method of scoring the relationships between groups of propositions is demonstrated. Takeya, Sasaki, Nagaoka & Yonezawa (2004) developed a formula to compare student maps to maps of teachers. Mls (2006) proposed scoring maps based on the spatial relationships in the maps. Mls developed a formula to measure the spatial distance between concepts, and hypothesized that the greater the distance between concepts the less the learner actually understood about that concept. In contrast, Ruiz-Primo (2004) proposed that to use concept maps as an individual assessment tool requires that the assessment be based on the task to be mapped, the response format required by the instructor, and the scoring system. Ruiz-Primo advocates that the degree of directedness of the maps needs to be considered in the assessment. By this she means was there high direction in the mapping task (fill in the blank maps) or low direction (maps totally constructed by learners). Finally, Khamesan and Hammond (2004) move the understanding of scoring maps forward by proposing three levels of measuring learning effectiveness with concept maps: individual learning, whole group learning, and interaction between the group and the individual. They propose a taxonomy in scoring that differentiates which concepts were created at the individual level, from new concepts that were created at the group level. They also propose a method to analyze which concepts were transfer or rejected between the individual and the group. This work supports efforts to understand how learning differs at the individual and group level.

In addition, concept maps were used to provide program assessment. In these studies, maps were used to analyze what concepts were being taught and how those concepts were being evaluated. In some papers authors discussed how concept maps were used to align curriculum with state standards. Heinze-Fry and Ludwig (2006) used concept maps to align a public school elementary life science program within the framework from the state. They designed a template concept map to demonstrate where the local program fit with the state standards. Similarly, Carnot, Gaudet, and Hinesley (2006) used concept maps in a psychology program to prepare for an accreditation visit by linking course learning goals and program goals. Additionally, the CmapTools software capability for resource files to be linked to maps is expected to be useful in this process as well.

4.3 Knowledge Development

Knowledge development was the third area where concept map research was conducted in the 2004 and 2006 conferences. The broad category of knowledge development includes knowledge modeling, knowledge elicitation, knowledge recovery, the development of team mental models and the development of knowledge management systems. Concept maps have been used in all of these areas to significantly advance our understanding of how knowledge develops within individuals, groups and organizations. In the areas of knowledge elicitation and knowledge recovery, Coffey, Eskridge, and Sanchez (2004) describe how concept

maps were used to elicit knowledge for the preservation of institutional memory in the nuclear power industry. Coffey (2006) then goes on to describe techniques for the creation of concept maps with a subject matter expert and a concept map facilitator. Beuter and Pinto (2004) also provide samples of knowledge elicitation techniques that can be selected based on the type of knowledge to be elicited, the software available, the sophistication of the client, and the type of problem for which knowledge is generated. Hoffman and Eccles (2004) report on the development of a large knowledge model made up of over 150 concept maps. They indicate that the process of knowledge recovery is very costly when considering the time and effort needed to create knowledge models. They suggest that organizations make knowledge capture an on-going part of their work rather then trying to elicit and recapture knowledge at a later date. In contrast to these authors, Freeman (2004) in a study comparing three treatment groups of analysts and users working together found that concept maps did not assist the analyst during requirements elicitation. Freeman's findings are in stark contrast to other researchers working in this area and he suggests that additional studies need to be conducted to determine if concept mapping and requirements elicitation can be combined effectively.

Concept maps have also been incorporated into the study and development of team mental models. Evans, Harper, and Jentsch (2004) hypothesized that teams exhibiting both high levels of expert knowledge and familiarity with teammates would perform at higher levels. Bowen and Mayer (2006) described how concept maps were used with a newly formed Board of Directors to create shared vision, map core values, and to develop a governance structure. Basque and Pudelko's (2004) research examined the effect of dyads developing knowledge models. They found a tendency that working at a distance in a synchronous fashion was beneficial to the development of team mental models. Keller and Tergan (2006) found that computer-supported collaborative learning, using the KIA-tool for concept mapping, lead to better collaboration and more efficient problem solving in groups. Johnson et al. (2006) compared four research methods for studying concept maps and the development of individual and group mental models. Their study found that various models are needed to understand the complexities of how team mental models develop.

Finally, concept maps have been used to develop knowledge management systems in organization such as banking (Fourie & Schilawa, 2004), the chocolate history project at University of California-Davis (Lange & Grivetti, 2006), and to develop an understanding of consumers branding knowledge (Reesink, 2004). According to Briggs, Shamma, Cañas, Carff, Scragle, and Novak (2004), concept maps can also be used to develop a library of concepts accessible to the general public. They describe the CMEX Mars indicating how concept maps were used to create a knowledge management system to describe all aspects of Mars exploration.

4.4 Software Development

Another theme that emerged from the conference papers is the development, testing, and application of software programs in different parts of the world. In Spain, the ARK.I.NET software was designed to allow users to collaboratively construct knowledge at the concept, theme, relation, and map levels (Madrazo & Vidal, 2004). In Norway, Cerpus AS developed Brainbank Learning, a web based application that represents a systematic way of constructing and documenting knowledge during the learning process (Salazar & Renauld, 2004). In Germany, computer-based concept map software was developed and applied to the subject of music (Weyde & Wissmann, 2004). In Greece, a web enabled concept mapping learning environment, Compass, was created to support multi-feedback forms and components adapted to learner's characteristics (Gouli, Tsakostas, & Grigoriadou, 2006).

In Chile, software was designed and re-designed according to teachers' pedagogical needs and to implicit cultural requirements of Chilean schools (Sánchez & Alarcón, 2004). In Argentina, Moroni and Señas (2006) proposed a new form of visualizing programs using Pascal Language in order to make information more meaningful for the viewer. In Costa Rica and Cuba, software programs were analyzed to review their advantages and disadvantages (Simón, Estrada, Rosete, & Lara, 2006). In Venezuela and Spain, ATLA/ti software was developed to construct concept maps to analyze the complexity of teaching math (Bencomo, Godino, & Wilhelmi, 2004). In Australia, Gomez (2006) developed a symbolic mapping apparatus for use in the early childhood classroom.

In the U.S., the software "counselor," using a case-based algorithm, was developed to offer suggestions for layout of concept maps (Brenes & Valerio, 2006). Luckie, Harrison, and Ebert-May (2004) described the concept map scoring software C-TOOLS, created to develop and validate a new assessment tool, the Concept Connector, consisting of a web-based concept mapping Java applet with automatic scoring and feedback functionality. Leake, Maguitman, and Reichherzer (2004) described the development of the CmapTools concept

suggester, an effective tool in early concept mapping. Clariana and Koul (2004) explained the software tool called ALA Reader to translate short passages into maps.

4.5 Professional development

Concept maps have also been used in numerous countries to foster the professional development of teachers. The maps have been used to help teachers understand subject matter content and to assist teachers in focusing more on student learning. Maps were also used to assist in the development of lesson plans and to foster a deeper understanding of teacher beliefs. Studies also indicated that when teachers learned to use concept maps their teaching approaches and teaching beliefs changed. For example, Leou and Liu (2004) conducted an eight year case study of experiences of math teachers, finding that concept maps assisted the teacher to change from the deliverer of content into the communicator and distributor. In this study, math teaching changed and effectiveness increased as the participant gained more self-confidence. Bermejo (2004) used concept maps to assist teachers in developing their understanding of the philosophy of science. Conlon and Bird (2004) in a study in Scotland, found that concept mapping is not yet part of mainstream teaching practices, but they also found that most teachers regard mapping highly as a teaching technique. They conclude that with the right kind of support and increased staff development teachers can gain confidence to use mapping in their teaching and thus expand their teaching repertoire.

4.6 Research Methods

Finally, using concept maps as research tools was an area discussed by authors of CMC papers. It is interesting to note that Iuli and Helldén (2004) remind us that concept maps were originally developed as a data analysis tool to demonstrate how children's understanding of science grew and changed during a longitudinal study. Iuli and Helldén go on to describe four research studies in which they use concept maps as part of the methodology. They state, "In the first, concept maps were used as a tool for analyzing interview data of students' understanding of ecological processes over a six year period. In the second, concept maps are being used to compare individual students' understandings of the transformation of matter with students' shared understandings. In the third study, concept maps were used as a research tool by a team of research scientists. They were found to help some members of the team to identify research questions that guided their individual research project. The fourth study is using concept maps to investigate the development of students' conceptual understanding of science in environmental problem solving based courses at colleges and university across the U.S." (p. 367). Additionally, Carnot (2006) describes the use of concept maps as a way to organize literature reviews for two large scale projects. Cahuzac and LeBlanc (2004) discuss how concept maps were used during an anthropological field study to explain mental representations of participants. Finally, Daley (2004) provides examples of how concept maps were used in qualitative research to frame research projects, reduce data, analyze themes, and present findings. She goes on to indicate that the advantage of using concept maps in qualitative research is linked to maintaining the meaning of the data in a unique context, but the disadvantage may be the complexity of the maps. What this work demonstrates is that concept maps have a role to play in both quantitative and qualitative research methods in a variety of disciplines.

5 Implications for Future Research

As demonstrated in this review, the research on concept mapping has expanded significantly with the advent of the International Concept Mapping Conferences. The CMC has provided an avenue for dissemination of concept mapping research from around the globe. Based on our review of the CMC proceedings and the themes identified in this paper, we envision a bright and exciting future for concept mapping research. It appears to us that additional research is needed in a number of areas. Based on our work here, we advocate that the next generation of concept mapping studies be designed to push the research forward into areas that have been neglected or under-explored.

First, it is well documented that concept maps are an effective instructional strategy across various ages of learners within a variety of disciplines. We know that concept maps support learning in both a cognitive and constructivist fashion. Additionally, we know that for concept maps to be used effectively teachers/faculty need to be able to shift their style of teaching and/or their beliefs about teaching and learning. What we do not fully understand, however, is the resistance to mapping on the part of some learners and some teachers. Does this resistance come from an inability to change learning and teaching strategies, or does this resistance emanate from innate learning styles? We also do not fully understand how concept mapping integrates with other thinking and learning processes such as deep learning processes, developing mental models, critical thinking, clinical reasoning, and diagnostic reasoning. Additionally, the field could benefit from research on how concept

mapping can be used in on-line and hybrid course, as well as, how concept mapping may facilitate learning when paired with other technologies such as learning objects and PDAs.

Second, we suggest more research in the area of group learning with concept maps. Studies have shown that shared mental models can develop through collaborative learning and from the interaction of individuals in the development of a group map. However, the processes that groups use to build from individual maps to a group map need more investigation. Additionally, we need to understand more fully how teams and groups construct knowledge and then how that process of knowledge construction facilitates the performance of the group. When groups and teams develop a shared mental model with concept maps, how does their performance compare to groups who have not engaged in this process?

Third, our review indicates that one of the most neglected areas of research in concept mapping is in the conduct of longitudinal studies. Most of the studies with concept maps show that learners change over the short term, but other than Novak's (2004) original 12 year study there are very few longitudinal concept mapping studies. In this review one study (Daley, 2004) followed students for a year to assess their continued use of concept mapping, however, even this can be considered short term. Longitudinal studies of learning outcomes based on concept mapping are greatly needed across many disciplines and with a variety of learners.

Fourth, the use of the CmapTools software needs continued research. As this software continues to be developed the innovations that are added to the program need to be assessed and evaluated. For example, the effectiveness of the concept suggester and the Cmap recorder need further research. It would be most interesting to investigate if we can understand how a learner's thinking develops and/or changes by assessing each step in map construction through using the Cmap recorder.

Fifth, a neglected area of research seems to be in the connection of concept mapping and culturally relevant teaching and learning. There were a few studies in the conference proceedings that mentioned that maps could be used to build communities of diverse learners, but this was not really studied in depth by any of the researchers. It would be interesting to understand more about how different racial or ethnic groups use concept maps in their learning. Can our teaching be more relevant to diverse learners through the use of maps?

Sixth, in this review there was a beginning analysis of different ways maps can be used in assessments and there were a number of scoring formulas proposed for concept maps. This entire area of assessment and scoring needs much greater development. How can we use concept maps to assess and document learning and/or change in meaning and understanding for learners? This is crucial as there is a great deal of focus on learning assessment within all levels of education. Can a scoring method be developed that clearly documents learning outcomes?

Seventh, we need to continue investigating the use of concept maps as research tools in both quantitative and qualitative studies. We need validity and reliability testing of concept maps compared to other measures of learning. Additionally, we need assessment of maps and their potential to contribute to quality control in qualitative studies.

Finally, research in the areas of knowledge development, knowledge modeling, and knowledge systems need to be expanded, especially within a variety of organizations. We need research to help understand how concept maps can function in analysis of job tasks, foster institutional memory, support the development of expert knowledge, and analyze social relationships and group conflicts. This type of research has the potential to help our profit and non-profit organizations function at increasingly higher levels.

In conclusion, as Ausubel indicates, "The most important single factor influencing learning is what the learner already knows. Ascertain this and teaching him accordingly" (as cited in Novak & Gowin, 1984, p. 40). As such our literature review is designed to document what we already know about the technique of concept mapping so that we can continue to move forward pushing our research and our own learning in new, uncharted directions.

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