

Individual versus collaborative computer-supported concept mapping: A study with adult learners

Clara Pereira Coutinho
Universidade do Minho – Braga – Portugal
ccoutinho@iep.uminho.pt

ABSTRACT

In this paper we report how two groups of in-service teachers used concept mapping for studying the curricular subject *Research Methods in Education* as part of a post graduate teacher education program during the 1st semester of 2008-2009. Teachers build electronic concept maps as a constructivist learning strategy to organize and reflect on the course readings, to plan assessment projects and to compare and contrast information of classroom discussions. Concept maps were built using CmapTools software individually (group A) and in teams (group B) on the same topics of the RME program. Concept maps were analysed considering five dimensions reported in literature: total n° of concepts, n° of valid links, hierarchical levels, cross links, examples and map visual format (vertical/horizontal/radial). Results show that individual maps are more diversified in terms of visual representations; that collaborative maps score higher in all five dimensions considered in the analysis; and that statistical differences are found when applying the Novak and Gowin (1984) formula to the concept maps due to the presence of more cross-links presented on group maps when compared to individual ones.

KEYWORDS

Concept mapping, individual, collaborative, CmapTools

INTRODUCTION

The Internet changed the way we teach and learn. Such revolution came to fulfil the needs of communication in many educational settings in particular those related to distance education. The emergence of online learning for education and training harnessed the use of the information technologies while it minimized physical and distances barriers increasing the possibilities of communication and interactions between instructor and learners. However, these new learning environments are exigent when it comes to the new roles it demands for both instructor and student. In e-learning environments students are induced to be active agents of the learning process and not passive consumers of the information. As to the instructor the matter is to plan effective learning activities either for individual or group use, to promote interaction, and to encourage students' meta cognition skills in order to improve learning: "If the design of courses allows individual exploration coupled with reflection and the comparison of a student's views with others, as well as the encouragement of good learning behaviours, then metacognition can be enhanced and good learning can result" (Fetherston, 2001, p. 15).

The use of concept maps has shown effective to promote a constructivist learning approach that helps learners to understand the learning processes of linking and creating meaningful schemes in the construction of knowledge. Research reports on the use of computer-based concept mapping as cognitive tools (Jonassen & Reeves, 1996), suggesting that these techniques could be successfully used to enhance teacher's higher order thinking skills as well as reflection about learning (Ferry et al, 1998; De Simone et al, 2001). One of the most promising uses of CM is its integration into group learning activities. In this situation the members of a group collaboratively construct maps. It supports discussion about concepts between members of a group. Computers and ICT have been used to support collaborative CM since the mid-1990s with promising results (Cañas et al., 2001). Several studies have investigated the effects of concept mapping on paper and computers, and concept mapping individually and collaboratively on paper and even collaboratively using computer software. Such studies have shown that concept mapping positively affects students' learning. When students have computer skills, computer-generated concept mapping also positively affects students' learning of concepts beyond concept mapping on paper. In addition, the literature indicates

that collaboratively generating concept maps on paper positively affects learning beyond individually generating concept maps (Royer & Royer, 2004; Kwon, & Cifuentes, 2007). However, as stated by Chiu et al., (2000), more research needs to be done on visualization comparing computer-based individually-generated concept maps and computer-based collaboratively generated concept maps to determine which strategy is most appropriate for adult learners in b-learning environments. This was the objective of the research presented in this paper: two different groups of teachers enrolled in a post graduate program in education built individual and collaborative computer generated concept maps using CmapTools Software. Maps built were kept on the CmapTools server as students built maps outside the weekly classroom sessions. At the end of the semester the teacher collected all maps posted in the server and analyzed them in order to find differences between the two modes of map construction.

CONCEPT MAPPING

According to De Simone (2001) concept mapping is a learning strategy that allows learners to externalize their thinking in a visual/verbal form to improve students' understanding of learning. It allows the learner to abstract important information, relate ideas, and represent them in a structured manner. The result is a concept map where concepts are enclosed in nodes and attached by links (Novak, 1998). Much work has been done in this area investigating the effectiveness of the strategy (Basque & Lavoie, 2006). Generally speaking, positive results have been reported (Novak, 1998; De Simone et al), although findings are not consistent across the literature. To better understand why and when concept mapping facilitates learning, De Simone & Schmid (1998) analysed the concept mapping process to uncover factors that could impinge upon the learner's use of the strategy. A relationship between the use of concept mapping as a tool and the levels of cognitive processing engaged in by the learners has been identified. Three types of strategy use emerged. Some learners essentially used standard mapping procedures that resulted in basic comprehension. Others displayed more creative mapping which sometimes led to higher level processing such as relating ideas in ways other than those suggested by the text, and more active monitoring of the comprehension process. Finally, some used the tool inappropriately and thus often faltered even at the basic level of processing.

The learning theory underlying the educational use of concept mapping falls under the general rubric of constructivist thinking. Constructivists make several assumptions about the learner, the context within which one learns the learning process, and the outcomes. Learning environments are most effective when they involve active learning, in which students solve problems, answer questions, formulate questions of their own, discuss, explain, debate, or brainstorm during class (Felder & Brent, 2003). Active learning is generally defined as any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing (Prince, 2004). While this definition could include traditional activities such as homework, in practice active learning refers to activities that are introduced into the classroom. The core elements of active learning are student activity and engagement in the learning process. Active learning is often contrasted to the traditional lecture where students passively receive information from the instructor. In such contexts, knowledge is not abstract and out-of-context, but is presented and learned in ways that are genuine, calling upon situations and applications that allow learners to use the knowledge learned (De Simone, 2001). Constructivists also purport to present learners with learning strategies, or flexible tools. Due to the nature of such constructed and authentic environments, it is assumed that complex strategies such as concept mapping can support the construction of genuine knowledge via analysis, drawing of inferences both within text and beyond the text through elaboration with prior knowledge (De Simone, 2001).

COLLABORATION IN CONCEPT MAPPING

The term "collaborative learning" refers to an instructional method in which students at various performance levels work together in small groups toward a common goal. The students are responsible for one another's learning as well as their own. Thus, the success of one student helps other students to be successful. Collaborative learning is fundamentally different from the traditional "direct-transfer" or "one-way knowledge transmission" model in which the instructor is the only source of knowledge or skills (Harassim,

2000). In collaborative learning, instruction is learner-centred rather than teacher-centred and knowledge is viewed as a social construct, facilitated by peer interaction, evaluation and cooperation. Therefore, the role of the teacher changes from transferring knowledge to students (the "sage on the stage") to being a facilitator in the students' construction of their own knowledge (the "guide on the side"). Some examples of collaborative learning activities are seminar-style presentations and discussions, debates, group projects, simulation and role-playing exercises, and collaborative composition of essays, exam questions, stories or research plans (Hiltz, 1994; Jobring, 1999). This new conception of learning shifts away the focus from the teacher-student interaction to the role of peer relationships in educational success (Johnson & Johnson, 1989).

Many authors recognize the innovative potentiality of the collaborative learning in the development of educational distance learning processes supported by digital communications network. Some even mention the appearance of an educational paradigm capable of answering the needs of learning in virtual environments (Harassim, 2000). Some of the essential bases that some persons relate to the change of the pedagogical paradigm are the emphasis given to the learning processes, reinforcement of teacher/student interaction, inclusion of cooperative work strategies, learning based on autonomy and reflection, which seem to integrate some of the most conscious proposals to use pedagogically new technologies and to create cooperative distance learning environments as answers to the demands of learning and education throughout the years (Meirinhos & Osório, 2006).

The positive effects of concept mapping to support online learning activities is well reported in the literature (Okada & Santos, 2005; Coutinho & Bottentuit Junior, 2008a, 2008b; Silva et al. 2009), as well as the use of CM to support collaborative learning activities (Chiu et al. 2000; Kamesan & Hammond, 2004). However most studies report research on collaboration on CM but related to face-to-face classroom activities. Kwon, & Cifuentes (2007) recommend that more research needs to be done and this study intends to contribute to the state of the art.

The CmapTools software (available for download at: <http://cmap.ihmc.us>) developed at the Institute for Human and Machine Cognition brings together the strengths of concept mapping with the power of technology, particularly the Internet and the World Wide Web (WWW) (Novak & Canas, 2004). The software allows the user to link resources (photos, images, graphs, videos, charts, tables, texts, WWW pages or other concept maps) located anywhere on the Internet to concepts or linking words in a concept map through a simple drag-and-drop operation. Links to these resources are displayed as icons underneath the concepts, and by clicking on one of these icons will display a list of links that the user can select from to open the linked resource (Canas et al, 2004). Using CmapTools, it is possible to use concept maps to access any material that can be presented digitally, including materials prepared by the mapmaker. In this way, concept maps can serve as the indexing and navigational tools for complex domains of knowledge (Cañas et al., 2001). According to Novak and Canas (2006) CmapTools was designed to support collaboration and sharing and can be used either for face to face activities as well as for distance learning.

The CmapTools software brings together the strengths of concept mapping with the power of technology, particularly the Internet and the World Wide Web (WWW) (Novak & Canas, 2004). The software allows the user to link resources (photos, images, graphs, videos, charts, tables, texts, WWW pages or other concept maps) located anywhere on the Internet to concepts or linking words in a concept map through a simple drag-and-drop operation. Links to these resources are displayed as icons underneath the concepts, and by clicking on one of these icons will display a list of links that the user can select from to open the linked resource (Canas et al, 2004).

METHOD

The study we present in this paper was developed in the first semester of 2008/09 and enrolled two groups of in-service teachers who attended a program on Research Methods in Education (RME) as part of a Master Degree in Education. For one semester teachers were taught to use concept maps as an integrated part of their course work. They developed concept maps to reflect on the course readings, plan course projects and to compare and contrast information from class discussions. In fact, the complexity of the subjects claimed for the search of learning activities requiring deep engagement of the student with learning materials and concept mapping was the mind tool used to enhance learning (Jonassen, 2007).

The RME course took place throughout 15 weekly face to face sessions of 3 hours each, followed by at-distance activities. The at-distance activities were aimed at finalizing the didactic-pedagogic activities carried out during the weekly meetings, and all teachers used this period to build the CMs.

The researcher was the instructor in both groups and the CmapTools software was used to map the main topics of the RME program. All concept maps created were posted online in the CmapTools server for the instructor and colleagues to visualize and leave comments as the learning activity was considered for final assessment. One group of teachers (A) used the software to build individual maps; the second group (B), in small groups (2 or 3) teachers used the software to build collaborative maps. Two curricular subjects were selected for the maps analysis: "Sampling" and "Methods for data collection", so individually or in groups teachers built maps, one for each topic. 29 teachers (11 in Group A and 18 in group B) participated in the study. 68% were female and 32% were male. As to age, the range 30-40 was the most represented in the sample. Teachers in group A build 22 individual maps; teachers in Group B build 16 maps on the same curricular topics. A total of 38 maps were gathered and considered for the study.

Various methods of analysis of concept maps have been described in the literature. If each concept is only mentioned once on the concept map, then it is easy to count how many links each concept has to and from other concepts. The number of links with other concepts is a good estimate of centrality of that concept in the thinking of the person whose thoughts are concept mapped. A commonly adopted scoring procedure is that proposed by Novak and Gowin (1984, pp. 36-37) and it consists of the following rules:

- any relationships that are valid score 1 mark each;
- every valid level of hierarchy scores 5 marks each;
- cross links if valid score 10 marks each. If the cross link is valid but does not illustrate a synthesis between sets of related concepts and propositions it only scores 2 points;
- examples score 1 mark each.

In order to guarantee the reliability of the coding process, two independent raters (the researcher and a colleague) evaluated a random sample of 5 maps. A 78% of agreement was obtained, what, according to the literature, is considered to be a reasonable percent of agreement that assures the reliability of the coding process (MacMillan & Schumaker, 1997). All concept maps were analysed and results were computed using SPSS software.

RESULTS

The first overall remark of the analysis of the 38 concept maps was the variety of the visual formats obtained. In fact, although mapping the same topics, all maps were somehow different from each other. All were valid interpretations of the curricular topics, but authors profited from the software facilities to create a map that was unique in itself. Some used different colors to mark up the hierarchical levels, others used different shapes for concepts, for links and for examples.

According to the literature, the concepts in a map should be represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below. Novak and Gowin (1984, pp. 16-18) demonstrated how the same concepts can be arranged hierarchically in three different ways, depending whether the main concept is placed in the map, either at the top, at the left side or in the center. In fact, the same effect can be achieved if the most important concept is sometimes in the center of the concept map but sometimes somewhere else, as long as that choice can be justified to be the best option. Then, we may imagine the center of the concept map as the top of a pyramid seen from above (Novak, 1998).

All those formats were found in the maps that integrated the database. We then decided to consider the three formats reported in the literature and classified our maps into three categories according to the position of the main concept: a) vertical, if the main topic is at the top of the map; b) horizontal, if the main concept is at the left hand side of the map and c) radial, if the main concept is at the center of the map.

Table 1. Categories of concept maps according to the position of the main concept

	Frequency	Percent	Cumul. Percent
Vertical	27	71,1	71,1
Horizontal	4	10,5	81,6
Radial	7	17,5	100,0
Total	38	100,0	

We verify that the vertical was the dominant format for the concept maps (71,%), followed by the radial visual format (17,5%). The horizontal format was the least used by the participants.

If we relate the concept map format with the experimental condition (individual versus collaborative) we obtain data presented in Table 2.

Table 2. Format of concept maps according to the experimental condition

	Individual	Collaborative	Total
Vertical	13	14	27
Horizontal	3	1	4
Radial	6	1	7
Total	22	16	

We verify that vertical maps are dominant either when maps are individually or collaboratively built. However, we also see in the analysis of the data contained in Table 2, that alternative formats (horizontal or radial) are dominant in individual maps. It seems that when maps are built individually, the author dare trying out different visual shapes for organizing information; on the other hand, when built in groups the maps tend to adopt the classical format with the main concept at the top of the layout. However, we could not find in the literature any support for the results found in our study.

The 38 concept maps were then analyzed quantitatively considering the five dimensions reported in the literature: total n° of concepts, total n° of valid links, n° of hierarquical levels, n° of cross links and n° o examples (see Table 3).

Table 3. Means, standard deviation, maximum and minimum of quantitative analysis on concept maps

	Individual				Collaborative			
	Mean	Min	Max	SD	Mean	Min	Max	SD
N° Concepts	22,32	12	34	6,55	22,69	18	34	5,58
N° links	17,5	11	26	5,39	18,13	9	25	5,67
Hierarchical levels	6,91	3	13	3,49	8,19	4	10	2,31
Cross inks	0,27	0	2	-	2,13	0	6	-
Examples	12,8	0	32	11,6	15,63	2	26	8,5

We can verify that values in collaborative maps are slightly higher in all five dimensions in particular in what concerns to cross links and examples. On the contrary, the values of SD are lower in collaborative maps when compared to individual ones. However, when applying the *Student t test* for comparing the significance of the differences found in the dimensions considered for analysis, the values of probability obtained are higher than 0,05, so we have to admit that collaborative maps are not significantly different from individual ones in any of the five dimensions considered for analysis.

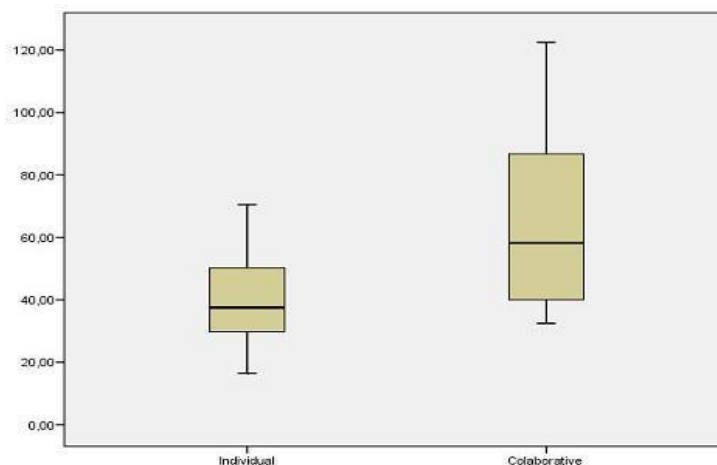
In the next step we applied the Novak and Gowin (1984) formula to the values of Table 3. Data obtained are presented in Table 4.

Table 4. Values obtained applying the formula to concept maps

	Mean	SD	Min	Max
Individual	39,68	17,16	16,5	70,5
Collaborative	65,62	31,09	32,5	122

Now the differences between the two groups of maps are evident; the Mean score for collaborative CMs is 65,62 and in individual maps that score is only 39, 68. Values of SD are also much higher in collaborative maps, minimum and maximum confirm a higher dispersion of scores when maps are built in groups. Figure 1 illustrates with a boxplot graph the results obtained and considered in Table 2

Graph 1- Boxplots comparing collaborative and individual CMs.



We can verify that collaborative maps have higher scores both for mean, median and standard deviation. The explanation for the observed results can be tried if we consider the influence of the higher scores in two of the dimensions highly considered for the calculation of the Novak & Gowin formula: hierarchical levels and cross links. In fact, those two dimensions score high according to the authors formula, and contribute significantly to the results obtained in the scoring of the concept maps considered in the analysis.

In order to test the significance of the differences found, a parametric *t test* for independent groups was chosen because the conditions for normal distribution were guaranteed in the exploratory analysis of data (Black, 1999). As shown in Table 5, the variations found in the scores are significant at the level of $p < 0,05$ what means that they are not due to random factors but to differences found in the data. However the value of the statistical difference is tangential ($p < 0,32$, assuming the equality of variance and $p < 0,52$ if that difference is not assumed) and so the results must be interpreted with care.

Table 5. Results of the t test for comparing means of individual versus collaborative concept maps.

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
TOTAL	Equal variances assumed	3,593	,075	-2,336	17	,032	-25,94318	11,10649
	Equal variances not assumed			-2,135	10,099	,058	-25,94318	12,14971

DISCUSSION AND CONCLUSION

The need to study the use of concept mapping for collaborative learning activities in b-learning environments motivated the research we report in the paper. Two groups of adult learners built concept maps on two curricular topics in two experimental conditions: individually versus collaboratively. The maps were built using CmapTools Software and an online space in the software server was used for teachers to build the maps. At the end of the semester concept maps were analyzed considering several attributes of good maps reported in the literature. 38 maps were analyzed (22 individual and 18 in groups). Results show that individual maps are more diversified in terms of the global visual representation, as the authors feel more free to choose the format to present the hierarchy of the concepts; on the contrary, all collaborative maps (except for 2) adopted the classical model of placing the main concept at the top of the map, with the subsequent concepts and links deriving from there.

The analysis of the characteristics of the two sets of maps show that collaborative vs individual maps score a little bit higher in all categories considered in the analysis (n° of concepts, links, hierarchies, cross-links and examples), but the differences found are not significant at the level of $p < 0,05$. However, when applying to the data the formula proposed by Novak and Gowin (1984) we verify that the total scores obtained in the collaborative maps score higher than in individual ones and that the differences are statistically significant (though tangential) at the level of $p < 0,05$. This means that we have reasons to believe that the interactions that occur in a collaborative team when building the same concept map on a specific topic helps the group to go further in the understanding of the content under study, and that explains why collaborative maps scored higher due to the presence of more cross-links presented on group maps when compared to individual ones. Cross-links help us to see how some domains of knowledge represented on the map are related to each other (Novak & Gowin, 1984); they show a higher level processing in relating ideas in ways other than those suggested by the text, and more active monitoring of the comprehension process. However much more research needs to be done in order to support the evidences found in this exploratory study.

ACKNOWLEDGMENTS

This paper presentation was financed by CIED, Minho University, Braga, Portugal.

REFERENCES

- Basque, J.; Lavoie, M-C. (2006). Collaborative Concept Mapping in Education: major research trends. In A. C. Canas & J. D. Novak (eds). *Proceedings 2nd International Conference on Concept Mapping*. San José, Costa Rica.
- Black, T. (1999). *Doing quantitative research in the social sciences: An integrated approach to research design, measurement and statistics*. London: Sage Publications.
- Cañas, A. J., Ford, K. M., Novak, J. D., Hayes, P., Reichherzer, T., & Suri, N. (2001). Online concept maps: Enhancing collaborative learning by using technology with concept maps. *The Science Teacher*, 68(4), 49-51.
- Cañas, A. J., Hill, G., Carff, R., Suri, N., Lott, J., Eskridge, T., Gómez, G., Arroyo, M., & Carvajal, R. (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 1st International Conference on Concept Mapping*. Pamplona, Spain: Universiad Pública de Navarra.
- Chiu, C.H., Wu, W.S., & Huang, C.C. (2000). Collaborative concept mapping processes mediated by computer. *Institute of Computer and Information Education, National Taiwan Teachers College*, 33 (2), 95-100.
- Coutinho, C. P.; Bottentuit Junior, J. B. (2008a). Using concept maps as cognitive tools in a Teacher Education Program. In C. Bonk, M.M. Lee & T. Reynolds (eds). *Proceedings of E-Learn 2008 Conference on E-Learning in Corporate, Government, Healthcare & Higher Education*, Nevada, EU: Las Vegas, pp. 2577-2584.
- Coutinho, C. P.; Bottentuit Junior, J. B. (2008b). Using concept maps with postgraduate teachers in a web-based environment: an exploratory study. *Proceedings of the Workshop on Cognition and the Web: Information Processing, Comprehension and Learning*. Granada: Universidade de Granada, 24-26 de Abril de 2008, pp.139-145. Disponível em <http://hdl.handle.net/1822/7811>
- De Simone, C.; Schmid, R. (1998). *A Different Look at Concept Mapping: understanding its processes*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

- De Simone, C.; Schmid, R.; McEwen, L. (2001). Supporting the Learning Process with Collaborative Concept Mapping Using Computer-Based Communication Tools and Processes. *Educational Research and Evaluation*, Vol 7 (2-3), p. 263-283
- Felder, R. M. & Brent, R. (2003). Learning by Doing. *Chem. Engr. Education*, 37(4), 282-283
- Ferry, B; Hedberg, J. & Harper, B. (1998). How do Preservice Teachers use Concept Maps to Organize Their Curriculum Content Knowledge? *Journal of Interactive Learning Research*, v9 n1 p83-104. Avail. <http://www.ascilite.org.au/conferences/perth97/papers/Ferry/Ferry.html>
- Fetherston, T. (2001). Pedagogical Challenges for the World Wide Web. *Educational Technology Review*. 9,1.
- Harassim, L. (2000). Shift happens. Online education as a new paradigm in learning. *Internet and Higher Education* (3), 41-61.
- Hiltz, S.R. (1994). *The Virtual Classroom: Learning without limits via computer networks*. New Jersey: Ablex Publishing Corporation.
- Jobring, O. (1999). *Online Learning Communities: a challenge for communication and learning in companies*. [Online]. Retrieved the 15/01/2007 <http://www.learnloop.org/olc/lobringolclima.pdf>
- Johnson, D. W.; Johnson, R. T. (1989). *Cooperation and competition: Theory and research*. Edina, MN: Interaction Book Company.
- Jonassen, D. H. (2007). *Computadores, Ferramentas Cognitivas - Desenvolver o pensamento crítico nas escolas*. Porto: Porto Editora.
- Jonassen, D. H., & Reeves, T. C. (1996). Learning with technology: Using computers as cognitive tools. In D. H. Jonassen (Ed.) *Handbook of Research on Educational Technology*. New York: Scholastic Press in collaboration with the Association for Educational Communications and Technology.
- Kamesan, A, Hammond N. (2004). Synchronous collaborative concept mapping via ICT: learning effectiveness and personal and interpersonal awareness. In A. J. Cañas, J. D. Novak, F. M. González, Eds. *Proc. of the First Int. Conference on Concept Mapping*. Pamplona, Spain 2004
- Kwon, S. Y., & Cifuentes, L. (2007). Using Computers to Individually-generate vs. Collaboratively-generate Concept Maps. *Educational Technology & Society*, 10 (4), 269-280.
- McMillan, J.; Schumaker, S. (1997). *Research in Education: evidence-based inquiry*. 6^a Ed. Boston: Pearson Education, Inc.
- Novak, J. D., & Gowin, D. B. (1984). *Learning How to Learn*. New York: Cambridge University Press.
- Meirinhos, M.; Osório, A. (2006). Colaboração e comunidades de aprendizagem. In L. PANIZO *et al* (Eds.) *Proceedings of the 8th International Symposium on Computers in Education*, (Vol 2), pp. 270-278.
- Novak, J. & Canas, A.J. (2006). The Theory Underlying Concept Maps and How to Construct Them. Retrieved the 24th November 2008 <http://cmap.ihmc.us/Publications/ResearchPapers/TheoryCmaps/htm>.
- Novak, J. (1998). *Learning, creating and using knowledge. Concept Maps™ as facilitative tools in schools and in corporations*. London: Lawrence Erlbaum.
- Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. New York: Cambridge University Press.
- Okada, A.; Santos, E. O (2005). Mapeando informação, trilhando e construindo redes de significados : notas sobre uma experiência de pesquisa e docência em educação online . *Revista FAEEBA* , vol. 14, nº23, pp. 73-90-
- Royer, R., & Royer, J. (2004). Comparing hand drawn and computer generated concept mapping. *Journal of Computers in Mathematics and Science Teaching*, 23 (1), 67-81.
- Silva, M.; Torres, P. ; Marriott, R.; Santos, E.(2009). Transformando informação em conhecimento na sociedade da informação: notas sobre a técnica dos mapas conceptuais e a pedagogia interativa. In: P. DIAS *et al*. (Org.). *O currículo e o digital*. 1^a ed. Braga, Portugal: Universidade do Minho, V. 1, p. 239-260.