Concept Mapping: Connecting Educators
Proc. of the Third Int. Conference on Concept Mapping
A. J. Cañas, P. Reiska, M. Åhlberg & J. D. Novak, Eds.
Tallinn, Estonia & Helsinki, Finland 2008

THE TEACHING VALUE OF CONCEPT MAPS

Jorge Valadares-Universidade Aberta–Lisboa, Portugal
Maria Teresa Soares-Escola Secundária Miguel Torga–Lisboa, Portugal
jvalad@univ-ab.pt, mtms@mail.pt

Abstract. This paper aims to defend the use of concept maps in science lessons. We begin by presenting a theoretical ground for the use of metacognitive instruments in lessons where it is meant to create a constructivist environment favorable to a meaningful learning, as well as to some features of the cooperative work and negotiation of ideas, which is the ground for the above mentioned environment. Afterwards we are going to present some empirical evidence which points to the value of the concept maps for a better learning of sciences.

1 Introduction

In the theory of learning of Ausubel, as in Novak's as well, the key-concept in the educational process is the one of the meaningful learning. This, as Ausubel says (2003), is "the human mechanism par excellence for the acquisition and storage of the huge quantity of ideas and information represented in any area of knowledge " (p. 81). The meaningful learning is a process where the new items of information are related to a relevant aspect that exists in the structure of knowledge of an individual" (Novak, 2000, p. 51). The pupil will only learn in a meaningful way if there is a substantive incorporation, neither literal nor arbitrary, of new ideas with the ones that already belongs to the cognitive structure. It is essentially in this character - non-literal and non- arbitrary - of the relationship of the learning task with the cognitive structure that lies the efficiency of the meaningful learning as a mechanism to transform and store information (Ausubel, idem).

Meaningful learning requires relevant learning structures, well organized, and an emotional commitment to integrate the new knowledge into the already existing one. Different studies have demonstrated that the information acquired in a context of meaningful learning is not only kept for a much longer time, but it can also be used much more successfully in the resolution of new problems (Novak and Cañas, 2004).

2 Theoretical ground of the teaching value of concept mapping

2.1 Concept Mapping

A concept map is a theory-driven graphic organizer (Trowbridge & Wandersee, 1998, pp. 115-126), where there are represented in a diagram hierarchically organized a body of concepts concerning a given topic, connected by means of linking words so as to build meaningful propositions. Even though at first sight the concept map seems to be merely another form of graphic presentation of information, its real use by an individual will let him see that it is a really deep and powerful tool (Novak & Cañas, 2004).

When a pupil makes a concept map on a subject or discusses a concept map made by one of his mates or a group, he shows ideas he already has about this subject and which often seem to be misconceptions. This way the teacher gets to know his pupils' ideas about objects and/or events, and the pupils are made to reflect on their own ideas, to argue based on them, thus realizing when they have or not any normative validity and, even, when they have or not any axiological validity, if the teacher can and is able to establish the conditions so that his pupils can check if their own ideas agree or not with the observations and the collected data of these objects and/or events. This activity of *metacognition* has proved to be extremely enriching, helping the pupils to progress conceptually towards the great scientific ideas that have got a great explanatory power. The metacognitive tools and, in particular, the concept maps (Novak's) also help the pupils to know the nature of knowledge production/construction better and better (Novak & Gowin, 1999; Moreira & Buchweitz, 1993).

The reflecting on and the negotiating of ideas among the pupils, based on the maps and the Vees, mainly when the teacher adequately leads them, help them to penetrate the structure and deepen the meaning of the knowledge items upon which those instruments were made.

These tools stimulate the reflective thought (Novak & Gowin, 1999), being able to become an excellent contribution to the building of a social cooperative and constructivist atmosphere. They are excellent to detect the pupils' early conceptions and to know their cognitive structures, which allows to teach constructively in agreement with them and become good tools for a formative evaluation (more retroactive), or even more forming (more pro-active), making the pupils recognize new relationships and new meanings among concepts and often stimulating their creativity (Novak, 2000; Valadares & Graça, 1998).

The map made by a pupil about a certain subject never has a final character. It gets better and better as the understanding of the *conceptual structure of the subject* by the individual who is making it improves, and the concepts about this subject improve. It is therefore "a diagram which is changing as the meaningful learning is taking place" (Moreira, 2000, p. 56). To make them, negotiate them, present them, remake them are processes which very much facilitate a meaningful learning.

2.2 Cooperative work

Learning is a personal construction where the cultural agents are essential for it. The constructivist concept considers teaching as "a combined process, shared, in which the pupil, thanks to his teacher's help, can show that he is getting more and more skilled and autonomous in problem solving, concept using, having certain attitudes, and in many other questions" (Solé & Coll, 2001, p. 22).

Thanks to the interaction and help from his teacher and mates, each pupil can work or carry on a task at such a high level of achievement he would not have if he were working individually (Vygotsky, 1991). Having *cooperative activities*, when it takes place in an adequate environment, enriches since it often leads to meaningful learning by the pupils. Different authors such as Bessa & Fontaine (2002), Johnson & Johnson (1994), Johnson, Johnson & Holubec (1994, 1999), Johnson, Johnson & Stanne (2000), Slavin (1995, 1999) refer to researches made in this area that point to advantages of using it in the classroom environment.

However, "stimulating the cooperative work is more than having the pupils work in group" (Bessa & Fontaine, 2000, p. 57), and it is not only to assign them a task, to tell them to help one another, to share materials to solve the problems belonging to performing the task and wait for the work to show up finished. It is crucial to strategically define a set of principles and rules and transmit them to the pupils, generating the conditions for them to respect and keep them, and, at the same time, to make all the partners become responsible for the best results possible (Johnson & Johnson, 1994; Johnson, Johnson & Holubec, 1994, 1999). Teaching the skills of the socialising process is also very important.

We have got experienced in using strategies of cooperative work according to the model of Johnson & Johnson – *Learning Together*, pretty flexible and adequate to the demand of the experimental work and where we tried to respect the demands needed for a good cooperation. The demands, which are interrelated, are the following ones: the existence of a positive interdependence; a considerable face-to-face interaction; the existence of an individual/personal responsibility, clearly perceived to meet the group objectives; the frequent use of interpersonal and small-group skills and frequent and regular evaluation of the functioning process of group work, to improve efficiency (Johnson, Johnson 1994; Johnson, Johnson, 1999; Johnson, Johnson, Holubec, 1994, 1999). These elements are shown on the following diagram (figure 1):

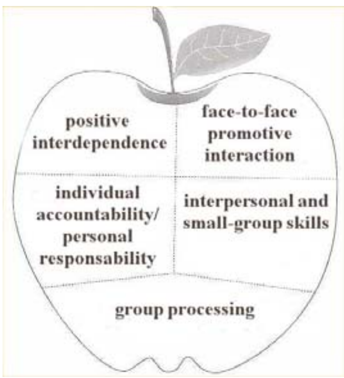

Figure 1- Essential components of cooperative work (Johnson, Johnson & Holubec, 1994, 1999, p. 38).

2.3 Constructivist and researching environments for learning

Taking into consideration the definition of a well-known theorist of learning environments, *B. Wilson* (1996), we can consider as a *learning constructivist environment* the environment where some “learners work together and support each other as they are using a variety of tools and sources of information following the way of learning objectives and problem-solving activities”.

The objectives of a constructivist environment, according to *Cunningham, Duffy* and *Knu*th (1993), are the following ones: to make the pupils familiar with the process of knowledge building; to afford the chance for approaching the questions and the living experiences under multiple perspectives; to implement learning in realistic and relevant contexts; to encourage the pupils to cooperate in the building of their own learning objectives and to become responsible for their own learning process; to provide collaborative activities, implementing learning in favorable social conditions; to use multiple forms for representing the situations involved in learning; to encourage the perception of the very process of knowledge building by means of reflexive and metacognitive activities.

On the other hand, Savery and Duffy (1996) have established the following four principles that should underlie the constructivist environments: (i) learning as an active and involving process; (ii) learning is a building knowledge process; (iii) the learners should work upon a metacognitive level; (iv) learning should involve “social negotiation”.

Following the ideas of Brooks & Brooks (1997, 1999) very close, we can say that in a constructivist environment the teacher will have to take into consideration the pupils’ viewpoints about the subject being studied, to provide activities which challenge the pupils’ assumptions, to discuss problems that the pupils think relevant, to develop strategies thought upon large and embracing concepts and to evaluate his pupils in the classroom context, on a daily basis and on a perspective as formative as possible. The pupils, in turn, should be active (but not hyper-active) researchers, intentional, dialoguing, reflexive and enlarging (Jonassen & Tessmer, 1996).

We have had direct and indirect experience that the metacognitive tools such as the concept map and the Vee of knowledge contribute to the establishment of good learning environments. When the concept maps are being made and remade and completed in a progressive way as the pupils are working within a teaching-learning unit, they are thinking in a metacognitive way, they themselves are regulating their own learning, and, at the same time, they are reflecting upon and building their knowledge in a collaborative way by means of negotiating ideas, and are evaluating themselves and the others, becoming co-responsible for their own learning’s.

3 Empirical evidence about the teaching value of Concept Mapping

Within the Master’s Degree in Science Teaching in the Open University different works were developed where there was the opportunity to research upon the effect of using concept mapping as a support for constructivist environments in the classroom, facilitating the meaningful learning. So, in a Master’s thesis it was made a quasi-experimental research where the pupils in an experimental class were subjected to a constructivist strategy based on the making of progressive concept maps and on a process of forming evaluation, and that strategy proved to be more effective for the learning of concepts of Mechanics of the school ninth level than a traditional strategy used in the control class, identical at the starting point, subjected to a similar teaching, with the exception of using concept maps. Besides a cognitive enrichment, which was seen in the evolution shown in the progressive maps and about them, there were developed among those pupils more favorable attitudes than among the pupils in the control class, as it was confirmed using a Lickert scale and a questionnaire to the pupils (Conceição & Valadares, 2002, pp. 217 - 232). We show, as an example, two concept maps made by the same student (figure 2). After comparing, it is worth noticing the evolution of the cognitive structure, even though there remain a few difficulties such as, for example, the non-connection of the mass to the inertia property of bodies (Conceição, 2002).

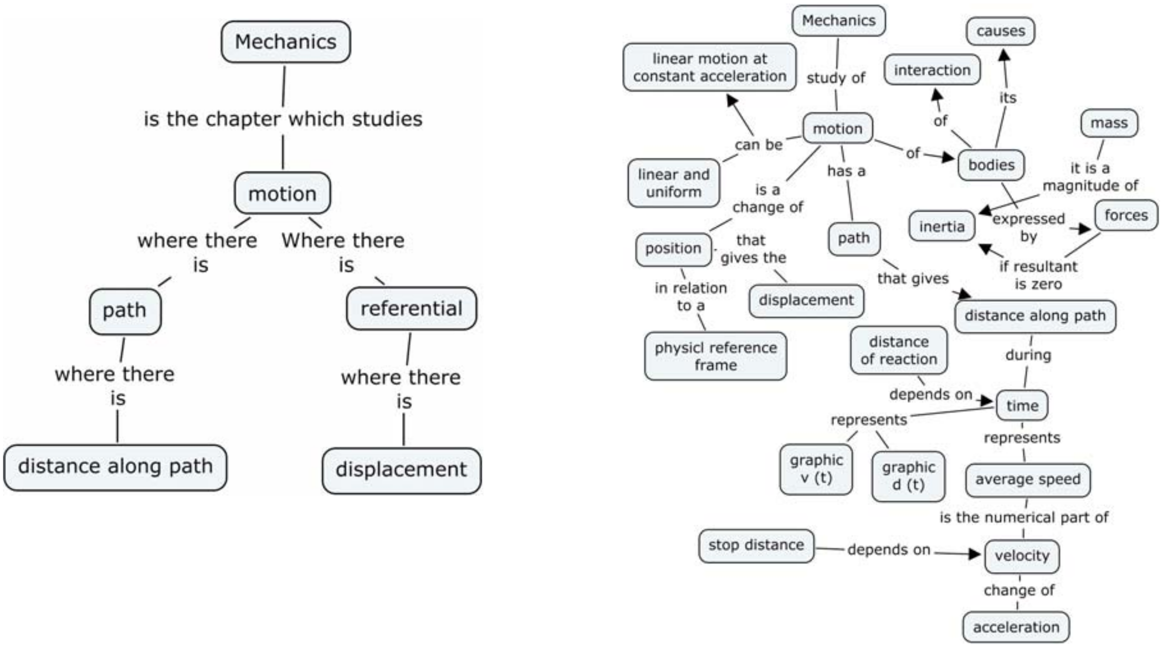

Figure 2- First and fourth concept map constructed by the same pupil (Conceição, 2002).

In another Master's thesis, a research was made based upon the use of progressive concept maps in lessons about human breathing for the Third Degree students of a Teachers' Course for the First Level of Primary teaching in a Superior School of Education (Ribeiro, 2004). The techniques and the researching tools were surveys made by questionnaire and interview, concepts maps made by the pupils as individuals and in a working method of cooperative group, observation grids, and the audio-taping of dialogues in a cooperative work context. Two groups were made, one experimental (n = 27) and another one of control (n = 27) and the researcher used a qualitative technique based upon the analysis of contents, either of concept maps or the answers to the surveys, with the purpose of cataloguing the misconceptions of the pupils in the two groups. Later she used statistical methods applying the SPSS Programme (Statistical Package for the Social Sciences) and Man - Whitney and Wilcoxon non-parametric tests.

While before the processing no meaningful differences between the two groups were found, after the activities with the progressive maps significative differences were found. And the comparison of the students' answers in the experimental group to the questionnaire after and before the activities of concept mapping showed significative differences in what refers to important features of breathing as the one of the ventilation, the lung capacity, the passage of the air in the body, the phenomena responsible for the alteration of the air and the substances that trouble breathing.

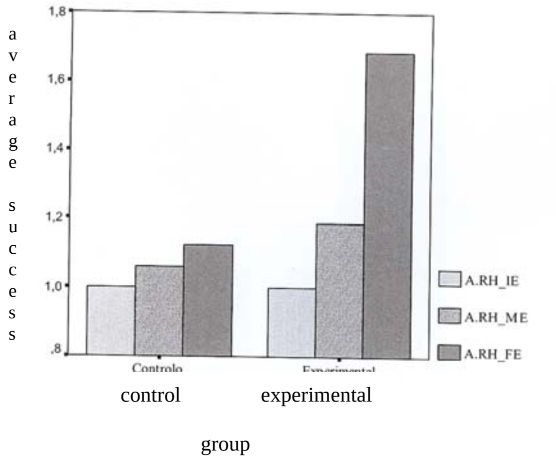

Figure 3- The success average in the sub-group questions "Substances which disturb breathing" in the first, second and third answering to the questionnaire. While in the control group the evolution was reduced, it was increased in the experimental group

The third research we refer to here was made in the Acoustics lessons, established by the curriculum of the Physical and Chemical Sciences of the Portuguese basic teaching level, and within a Ph. D. degree taken in the Open University. The data gathering was made according to the combination of a qualitative method, consisting of a remote and direct observation, with a quantitative method, based upon a quasi-experimental plan. The tools used for *data gathering* were these: a *pre-test* and a *post-test* about the contents of Acoustics; *questionnaires* answered only by the experimental class (EC), concerning the evaluation of performance during the group work, the evaluation of the global performance of the group work and, still, the evaluation of the activities made in the lessons; *observation grids*, one for collecting the data during the observation in the Acoustics lessons in both classes involved in the research, and another grid to evaluate the skills belonging to the cooperative work performed by the students in the EC, where this work took place. This grid was made following *Johnson & Johnson's* ideas (1999) about the cooperative work strategy "*Learning Together*", since this was the strategy used in fieldwork for this research; *the audio-taping* of the discussion held by the pupils in the work group; *concept maps* about Acoustics fundamental concepts; *the Gowin Vee* made in the experimental class to facilitate the constructivist environment; and, finally, a *semi-structured interview* with the teacher who was teaching Acoustics. These different information sources allowed data crossing.

On the following table we show the different steps of the concept mapping, the methodology we used, as well as the total number of maps made by the pupils in both classes (table 1):

Table 1- The making of concept maps by the pupils (Soares, 2007)

Moments	**Methodology**	**Experimental Class**	**Control Class**
Before teaching Acoustics	Individual	28 maps	27 maps
While teaching Acoustic	Cooperative work	30 maps	----------
After teaching Acoustics	Individual	28 maps	27 maps

As we can see on this table, during the research only the pupils in the experimental class did work in group and cooperatively, based on the concept mapping, while performing the proposed tasks concerning the Acoustics subject. The preparation of the pupils in both classes for the concept mapping was similar. Before the teaching of Acoustics, the pupils in both classes made concept maps about other subjects of Physics, so they could get familiar with this technique.

The Acoustics subject was divided into various sub-topics: the production of sound; the propagation of sound; the sound as wave; the sound properties; the sound listening. In the end of teaching each sub-topic, the pupils in each group made a concept map with the principal concepts in this topic whole, which was analyzed by the teacher and discussed in every one of the work groups in a cooperative way. The pupils' maps were being progressively self-corrected and enlarged with new concepts as they began studying new sections – progressive mapping – showing the process of structuring and restructuring of knowledge as the result of the discussion among the pupils, and between them and their teacher.

The introduction of the Vee into the empirical work of this research began to take place in a practical work to determine the sound speed, and after the pupils had become acquainted with the concept maps, as several authors suggest it, Moreira & Buchweitz (1993) among them.

The analysis of the concept maps made by the pupils was essentially qualitative and was focused on the features suggested by Novak (1998), Moreira and Buchweitz (1993), Valadares and Graça (1998), Novak and Gowin (1999) and Mintzes, Wandersee & Novak (2000), which are shown on the following table:

Table 2 - Qualitative evaluation of the concept maps individually made by the pupils (Soares, 2007)

	Before teaching Acoustics						**After teaching Acoustics**					
Avaliation / **Features**	Weak		Acceptable		Good		Weak		Acceptable		Good	
	TE	TC	TE	TC	TE	TC	TE	TC	TE	TC	TE	TC
Hierarchising of concepts	✓	✓						✓	✓			
Linear structure versus ramified			✓	✓							✓	✓
Relative number of concepts adequate connected	✓	✓						✓	✓			
Links words	✓	✓						✓	✓			
Cross links	✓	✓					✓	✓				

Taking this analysis as a basis, we could observe the cognitive evolution of the pupils in the experimental class. However, this analysis showed some aspects where the pupils found some difficulties. One of them was in establishing cross-links between the concepts. It is not strange that for the pupils at this age the integrating reconciliation of the concepts studied in this area is not easy. Among other reasons, we emphasize the fact that in Acoustics there are not many super-organized concepts dealt with at such a basic level. Another reason for this result was the difficulty the pupils showed in discriminating some Acoustics concepts such as, for example, the intensity of sound and the amplitude of the sound waves. As to the scientific accuracy of the relationships established among the concepts, we concluded that, generally speaking, it was pretty acceptable. We show, as an example, two concept maps made by the same work group in the experimental class (Figure 4 and 5).

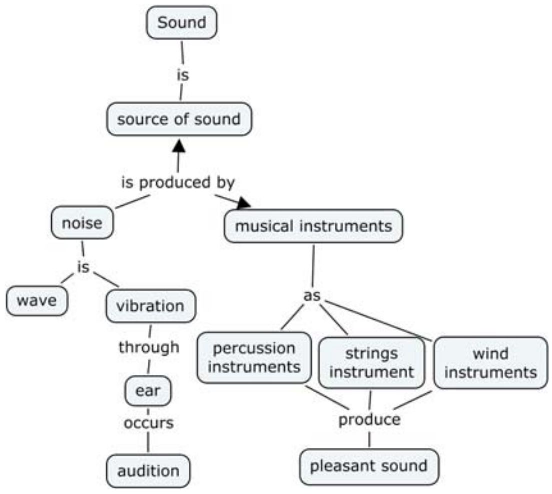

Figure 4 - A first map made by a group work after the teaching of the sub-topic sound production (Soares, 2007)

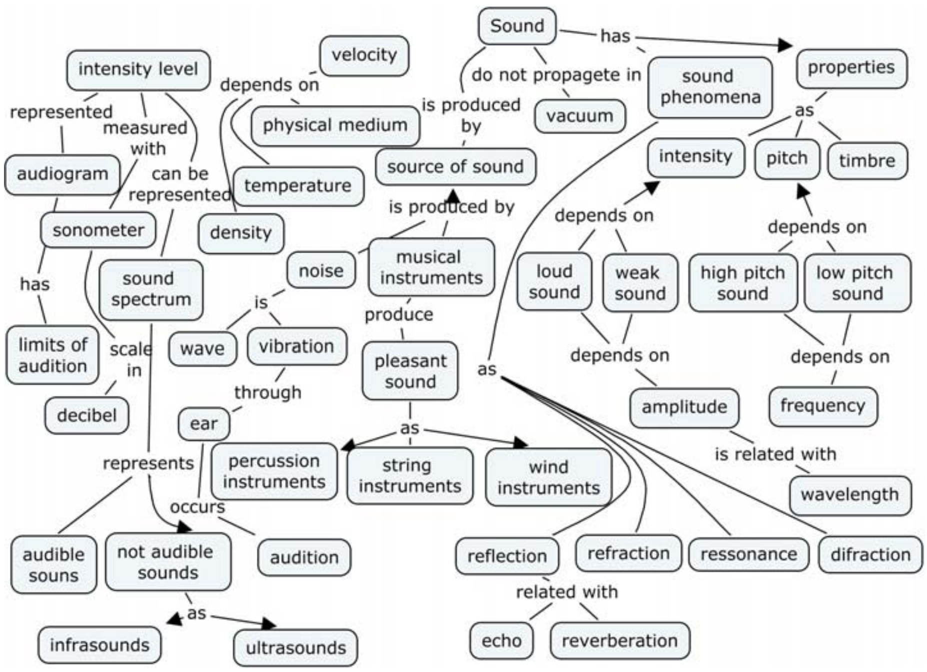

Figure 5 - A third mp made by the same group of students after study more subtopics about sound (Soares, 2007)

Both maps reveal some conceptual difficulties that have been discussed cooperatively in all the class. On comparing them, we found out that there was a reorganization in the second map of some of the concepts involved in the first one, as well as the introduction of new concepts, originated by the discussion among the elements in the group.

After the teaching of Acoustics, we compared the results obtained by the pupils in the two classes in the concept maps and in the pre-test, and we found out that the results in the experimental class (EC) were clearly positive and better than the ones in the control class (CC). As an example, we show on the following graph (figure 6) the departing situation of both classes and the arriving situation after implementing the constructivist and researching strategy in the EC and the traditional strategy in the CC.

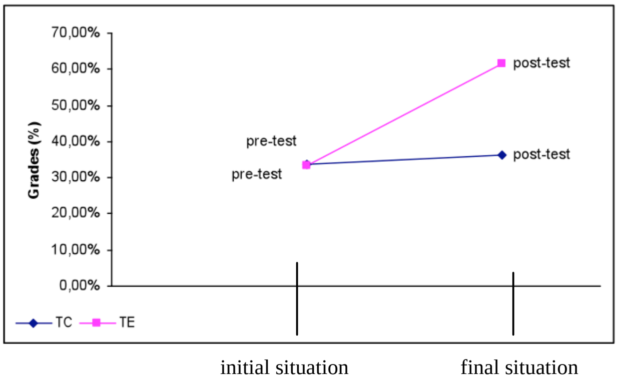

Figure 6 - Graphic presentation of the concept enrichment about the topic of Acoustics in the experimental class (EC) and in the control class (CC) (Soares, 2007)

On the graph we see an initial situation similar in the two classes and a final situation much more different in the same classes. The results of the post-test in both classes showed a better performance of the pupils in the experimental class.

Another of the collected results that confirmed the efficiency of the strategy used in the classroom were the answers by the pupils in the experimental class and in the control class to two questions in the post-test (questions 7.2 and 11), which were about the contents explored by making a Vee (sound speed). Then, the question 7,2 was formulated by this way: "A boat, being with difficulties of navigation, shot a rocket of advice. A lighthouse keeper, in the coast, heard a noise of the rocket 4 s after to have seen the flash. What is the distance of the boat to the coast?" To answer this question students would have to choose the correct answer in a group of four options, in this case the option D. The question 11 was this one: "It was produced a detonation in a quarry situated in front of a hill. The echo was heard just in the local of the quarry 3.0 s afterwards. At what distance was the hill?". Also in this question students had four options of answer. The correct option was C. The results of these two questions are shown on the following graph (figure 7):

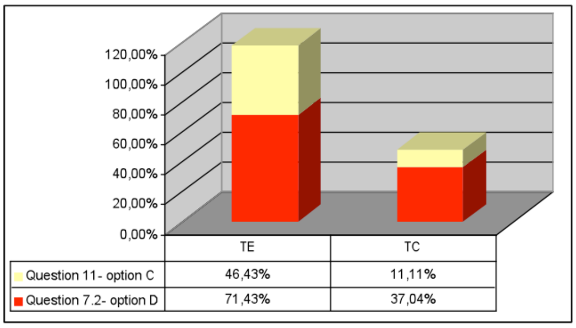

Figure 7 - Correct answers by the pupils in the experimental and control classes in questions 7.2 and 11 in the post-test (Soares, 2007)

As we can see on this graph, the pupils in the experimental class showed a better learning in any of the approached questions.

4 Conclusions

The main purpose of this paper was to show some research work made at the level of some Master's and Ph. D. degrees in the Teaching of Sciences by the Open University, which has given evidences that the teaching strategies developed in constructivist environments for learning, based upon the implementation of experimental activities and the use of metacognitive instruments, mainly progressive concept maps, but also Gowin Vees, lead to more meaningful learning than the use of strategies, even though experimental, in traditional environments. We think we can say that such strategies and environments, besides facilitating the meaningful learning of science, give the students a greater motivation for the study of sciences. As a matter of fact, beyond the results we have got, we have found out the commitment and the joy of the pupils in the experimental classes, while, in cooperative terms, they go on performing the proposed tasks. In spite of the evidences we have already come to, we think it is necessary to continue with more studies like these in other schools and other countries, considering the limited dimensions of the samples we have been working with, the result of the conditions of the very researches made in the classroom.

References

Ausubel, D. P. (2003). Aquisição e Retenção de Conhecimentos: uma perspectiva cognitiva. Lisboa: Plátano: Edições Técnicas.

Bessa N.; Fontaine, A. M. (2002). *Cooperar para Aprender*. Lisboa: Edições Asa.

Brooks, J. G.; Brooks, M. G. (1997, 1999). *Construtivismo em sala de aula.* Porto Alegre: Artes Médicas.

Cañas, A. J., Ford, K. M., Coffey, J., Reichherzer, T., Carff, R., Shamma, D., & Breedy, M. (2000). Herramientas para Construir y Compartir Modelos de Conocimiento basados en Mapas Conceptuales. Revista de Informática Educativa, 13(2), 145-158.

Conceição, L. (2002). Importância dos mapas de conceitos na aprendizagem de conceitos mecânicos no 9º ano de escolaridade. Dissertação de Mestrado em Ensino das Ciências – área de especialização: Ensino da Física. Lisboa: Universidade Aberta.

Cunningham, D. J.; Thomas, M.; Knuth, R. A. (1993). The textbook of the future. In C. Mcknight, A. Dillon & J. Richardson (Eds.) *Hypertext: a Psychological Perspective.* New York : Ellis Horwood.

Good R. & Berger C. (2000). O computador como um mecanismo poderoso para a compreensão da ciência. In J. Mintzes; J. Wandersee; J. Novak (Eds), Ensinando ciência para a compreensão - uma visão construtivista (pp. 194-207). Lisboa: Plátano, Edições Técnicas.

Gowin, D. B. (1990,1999). Educating. Ithaca, N.I: Cornell University Press.

Johnson, D.W; Johnson, R.T. An overview of cooperative learning.

In http://www.co-operation.org/pages/overviewpaper.html. Originally publisher in Thousand, A. Villa and A. Nevin (Eds), Creativity and Collaborative Learning; Brookes Press, Baltimore, 1994.

Johnson, D. W; Johnson, R. T. (1999). Aprender juntos y solos. Buenos Aires: Aique Grupo Editor S.A.

Johnson, D. W; Johnson, R. T.; Holubec, E. J. (1994, 1999). Los Nuevos Círculos del Aprendizaje: la cooperación en el aula y la escuela. Buenos Aires: Aique Grupo Editor S.A.

Johnson, D. W., Johnson, R. T., Stanne, M.B. (2000). Cooperative learning method: A meta-analysis. In http://www. clcrc.com/pages/cl-methods.html.

Jonassen, D. H.; Peck, K. L.; Wilson, B.G. (1999). Learning with Technology: A constructivist perspective. New Jersey: Merril/Prentice Hall.

Jonassen, D. & Tessmer, M. (1996/7). An outcomes-based taxonomy for instructional systems design, evaluation and research. *Training Research Journal, 2,* 11-46.

Moreira, M. A. (2000). *Aprendizaje significativo: teoría y práctica.* Madrid: Visor Dis.

Moreira, M.A. & Buchweitz, B.(1993).*Novas estratégias de ensino e aprendizagem*. Lisboa: Plátano Edições Técnicas

Mintzes, J. J. & Wandersee, J. H. (2000). Reforma e inovação no ensino da ciência: uma visão construtivista. In J. J. Mintzes; J. H. Wandersee; J. D. Novak (Eds). *Ensinando ciência para a compreensão - uma visão construtivista* (pp. 45-65). Lisboa: Plátano Edições Técnicas.

Novak, J. D. (1998). Learning, creating, and using knowledge: Concept Maps as Facilitative Tools in Schools and Corporations. Mahweh, NJ: Lawrence Erlbaum Associates.

Novak, J. D. (2000). *Aprender criar e utilizar o conhecimento.* Lisboa: Plátano Edições Técnicas.

Novak, J. D. & Gowin, B. (1999). *Aprender a aprender.* Lisboa: Plátano, Edições Técnicas.

Novak, J. D. & Cañas, A. J. (2006). The Theory Underlying Concept Maps and How to Costruct Them, Technical IHMC CmapTools 2006-01, Institute for Human and Machine Cognition, 2006. In http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Learning: Alternative Conceptions. In D. L. Gabel (Ed.), Handbook on Research in Science Teaching (pp. 177-210). New York: Macmillan.

Wilson, B. (Ed.) (1996). Constructivist learning environments: case studies in instructional design. New Jersey: Educational Technologies Publications.

Ribeiro, S. A. C. C. (2004). *Os mapas conceptuais progressivos como estratégia de aprendizagem significativa da respiração humana.* Dissertação de Mestrado (não publicada). Lisboa: Universidade Aberta.

Savery, J. R. & Duffy, T. M. (1996). Problem based learning: An instructional model and its constructivist framework. In Brent G. Wilson (Ed), *Constructivist learning environments: case studies in instructional design.* Englewood Cliffs, NJ: Educational Technology Publication.

Slavin, R. (1995, 1999). Aprendizaje Cooperativo, Teoría, Investigación y Práctica. Buenos Aires: Aique Grupo Editor S.A.

Soares, M.T.M. (2007). A aprendizagem da Acústica no Ensino Básico: uma pesquisa epistemológica e psicologicamente fundamentada. Tese de doutoramento em Ensino das Ciências – área de especialização: Didáctica da Física. Lisboa: Universidade Aberta.

Solé, I. & Coll, C. (2001). Os professores e a concepção construtivista. In Coll, C.; Martín E.; Mauri, T.; Miras M.; Onrubia J.; Solé, I.; Zabala A., O c*onstrutivismo na sala de aula* (p. 28-53). Lisboa: Edições Asa.

Trowbridge, J. E. & Wandersee, J. (1998). Oganizadores gráficos guiados pela teopria. In J. J. Mintzes; J. H. Wandersee; J. D. Novak (Eds). *Ensinando ciência para a compreensão - uma visão construtivista* (pp. 45-65). Lisboa: Plátano Edições Técnicas.

Valadares, J.; Graça, M. (1998). Avaliando . . . para melhorar a aprendizagem. Lisboa: Plátano Edições.

Valadares, J. (2001). Estratégias Construtivistas e Investigativas no Ensino das Ciências. Conferência proferida no Encontro «O Ensino das Ciências no Âmbito dos Novos Programas», na Faculdade de Engenharia da Universidade do Porto.