CONCEPT MAPS: A STRATEGY FOR THE DEVELOPMENT OF TECHNICAL REPORTS ON INDUSTRIAL ENGINEERING PROBLEMS

Catalina Ramírez, Wilson Flórez, Ricardo Barros
Industrial Engineering Department, Universidad de los Andes, Bogotá, Colombia
mariaram@uniandes.edu.co, w-florez@uniandes.edu.co, r-barros@uniandes.edu.co

Abstract. In this article we present a study case on the use of concept maps as a strategy for the development of technical reports on industrial engineering problems. These problems occur in complex, multidisciplinary environments that require the application of technical and social systems knowledge which is analyzed by an engineer in order to propose effective and efficient solutions. This case seeks to contribute to the development of engineers' skills through the construction of answers to investigative questions, based on a review of appropriate literature. To validate this contribution, the performance of students in the construction of these reports and concept maps was analyzed. A tool for measuring the students' perception of the utility and ease-of-use of the concept maps was also designed. The performance and perception results evidence the utility of the concept maps as a strategy for handling industrial engineering problems.

1 Introduction

With the purpose of contributing to the integral development of the industrial engineer's skills in the organizational field, a group of teachers and researchers designed the course Systemic Thinking in Organizations (PESO - *Pensamiento Sistémico en las Organizaciones*). This course is part of the Organizational Management module which seeks to provide industrial engineering students with enough resources to diagnose, design and structure different organizational systems. The PESO course expects students: (a) to understand the evolution of organizations; (b) to develop capacities for observing different organizational dimensions; (c) to know and apply systemic methodologies in order to observe and intervene in organizations; and (d) to develop competence in written expression, oral expression and research. These objectives are pursued through the activities that can be seen in the concept map of the PESO course (Figure 1).

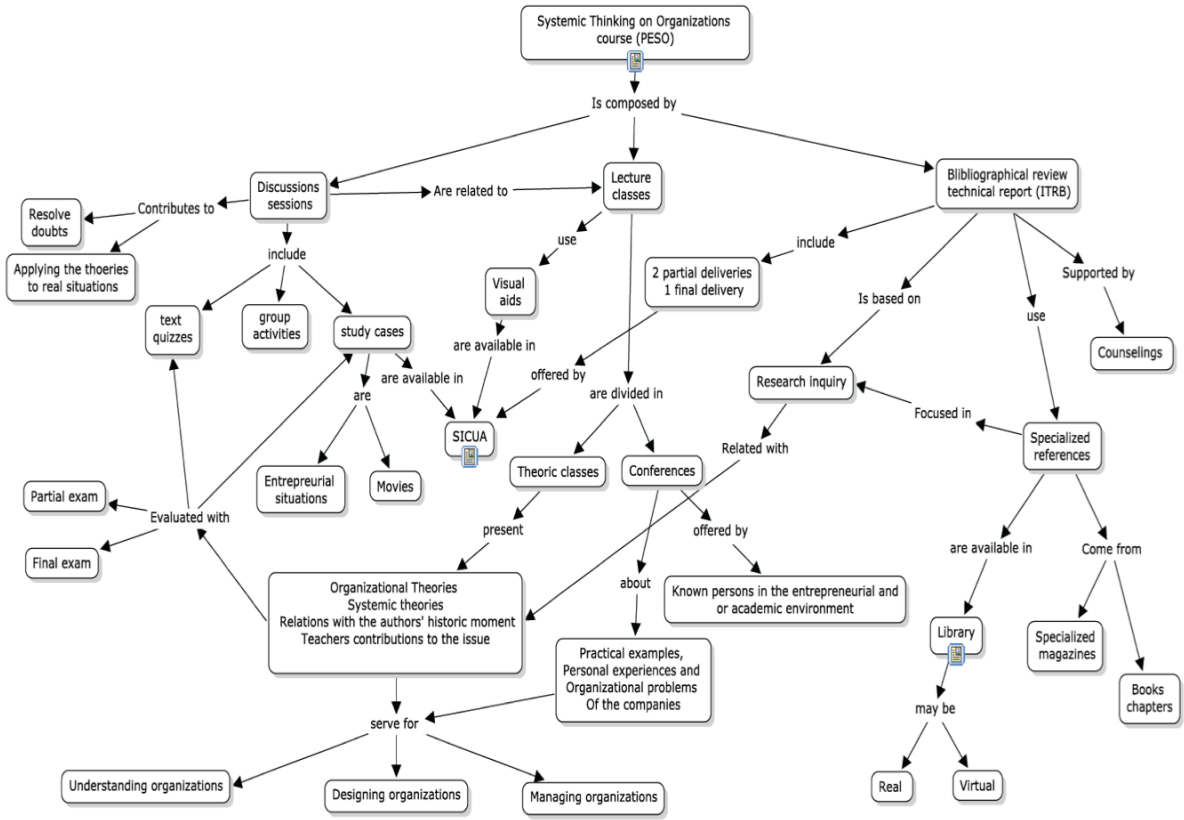

Figure 1. Concept Map of the PESO Course.

In order to attain the proposed objectives, particularly that related to the development of research, written expression and oral expression competences, a team of teachers and researchers have designed a tool called the Bibliographical Review Technical Report (ITRB - *Informe Técnico de Revisión Bibliográfica*). This is a report that seeks to strengthen the capacities of research and the approach to a specific situation from an engineer's technical perspective. It addresses a research enquiry related to the topics covered throughout the course and one of the teachers functions as a counselor for the students. It is executed in an entirely professional manner and has particular characteristics:

- it must be developed in two partial deliveries and a final delivery
- it must include an introduction, development and conclusion
- it must contain a definite number of words
- it must contain a definite number of references
- it must include a concept map of one of the investigated references and the different stages of the ITRB.

Each teacher posits a research enquiry relating to his/her sphere of interest and according to the investigation guidelines. The students have the opportunity of choosing one such enquiry and investigating it throughout the semester. Figure 2 displays an example of investigation topics suggested by the professorial team.

Research Topics (a brief list)	**Examples of Research Questions (2007)**
T1: Corporate Strategy	
	- How does the Balanced Scorecard contribute to the improvement of an organization's strategic capacity? (A. Reyes)
	- How do we develop a systemic process of stakeholders' identification? (J. Romero)
T2: Strategic Planning	
	- Can the evolutionary models approach the strategic planning processes in an organization properly? (C. Olaya)
	- How do we develop a systemic process of management control? (C. Ramírez)
T3: Information Technologies	
	- How do we develop a systemic process of information technologies adaptation in an organization? (R. Hernández)
	- How does the use of IT support the knowledge production in an organization? (W. Flórez)
T4: Organizational Learning	
	- How do we develop a systemic process of organizational learning? (J. Bermeo)
	- How do we develop a systemic process of collaborative work? (R. Barros)
T5: Knowledge Management	
	- How do we develop a systemic process of intangible activities measurement? (W. Flórez)
	- How do we develop a systemic process of knowledge production? (J. Cruz)

Figure 2. An example of Research Questions for the ITRB.

2 Theoretical Background

Given that one of the objectives of the PESO course is for students to develop competence in written expression, oral expression and research, it is necessary to justify the choice of technical report production as the right method to accomplish this objective. It is also important to clarify why the use of concept maps functions as a strategy to produce technical reports that supply theoretical solutions to common industrial engineering problems. Below are some considerations in support of these choices.

2.1 The ITRB as a tool for the development of communication and research skills

We consider that the ITRB enhances the identification, formulation and resolution of engineering problems, according to the ABET abilities proposal (ABET, 2003). Furthermore, the production of the technical report influences the development of written communication abilities. Additionally, the ITRB helps with the development of creative solutions to industrial engineering problems, through the understanding of the impact of these solutions and use of the necessary techniques to approach these problematic situations, as proposed by the National Academy of Engineering (NAE, 2004). Finally, in the development of the methodology for writing technical reports, the proposal made by Ashby (2000) was taken into account, especially with regard to the particular elements to be included in such reports. This implies a standardized review of the communication and research abilities observed in the students' ITRB.

Figure 3 highlights the different techniques used in the development of the ITRB that support the development of analytical and communicational abilities. This analysis is based on the proposals of the National Research Council (Bransford & Council, 2000) in the book *How People Learn*.

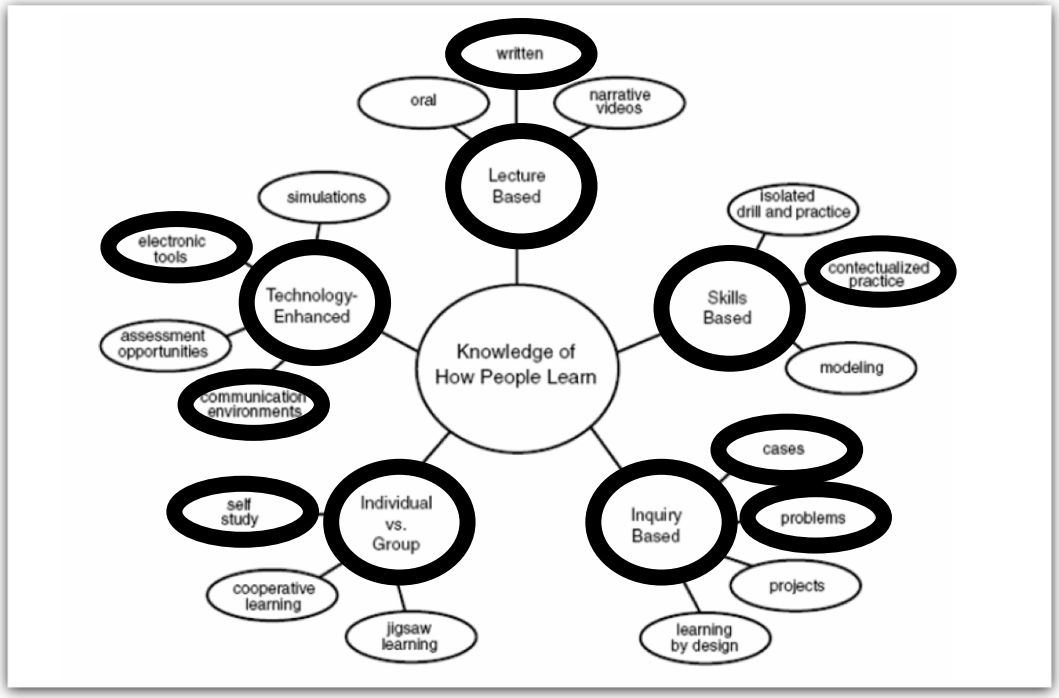

Figure 3. Knowledge of how people learn. The techniques included in the development of the ITRB are highlighted. (Adapted from Bransford & Council, 2000.)

2.2 Concept maps as a useful tool for the analysis of technical articles an approach to the research enquiry

After justifying the use of technical reports, we need to clarify the use of concept maps as a strategy for the production of these reports. First, the concept maps are graphic tools designed to organize and represent knowledge. Concept maps include concepts, relations between concepts and their hierarchy (the most general ones are placed above the less general) (Novak & Cañas, 2006).

Additionally, the concept maps become a useful tool for the analysis of technical articles since, according to Novak & Cañas, the concept maps are instruments that serve to organize and represent knowledge (Novak & Cañas, 2006). The student not only finds the most relevant concepts in the reading of the references but also generates semantic units related to the research enquiry. This articulation is facilitated through the construction of a general concept map which not only incorporates the most important concepts of the previous reading but also requires the construction of the interrelation between these concepts.

Two valuable characteristics of the concept maps in the analysis of technical articles are: (a) placing in a hierarchy the most inclusive concepts of the analyzed article (Novak & Cañas, 2006); and (b) a necessary element in the production of a concept map is the identification of a focus question (Novak & Cañas, 2006) that makes the student question the purpose of the author at the moment of writing the article and facilitates the relation with the research inquiry.

The group formed by (a) the research inquiry (focus question) and (b) the concept maps of the references generates the *context*, which is understood as a domain of knowledge that guides and defines the hierarchical structure of the general concept map (Novak & Cañas, 2006). Additionally, in the creation of new knowledge, the crossed links often represent creative leaps by the knowledge producer (Novak & Cañas, 2006). This additional element offers the possibility of generating creative leaps in the approach to an answer to the research enquiry.

Meaningful learning can easily lead to the generation of creative productions (Novak & Cañas, 2006), because generating a proposal to the research enquiry requires the students to have a relevant and well-structured knowledge base. The ability to construct an approach to a research enquiry in engineering based on the review of technical articles could hardly be obtained though mnemonic learning.

Finally, the production of concept maps facilitates examination of the assumptions that surround the statements of the authors of the particular references and helps to validate its integration in the answer to the enquiry. The concept maps encourage the process of reviewing and evaluating the assumptions. Several authors state that the concept maps are a useful tool not only for learning but also for evaluation: they are effective for identifying both the valid and invalid ideas that the students state in their approach and they facilitate review of the works delivered (Mintzes, Wandersee, & Novak, 2000; Novak, 1990; Novak & Gowin, 1984).

The evidence adduced above confirms that concept maps are a useful strategy for the analysis of technical articles and the construction of an approach to a research enquiry, processes that take place in the elaboration of the ITRB.

2.3 Production process of the ITRB and the concept maps

The purpose of the ITRB is the construction of an answer to a research enquiry related to common industrial engineering problems. In order to generate this answer an approach is constructed following these steps:

- choice of a research inquiry about an organizational issue
- review of literature specialized in the issue (search and documentation of pertinent sources)
- making concept maps of the articles
- making a concept map of the specific answer to the research enquiry
- composing the technical report that answers the research enquiry
- restarting the process twice, beginning with step 2, until the achievement of a third (and final) delivery of concept maps and a technical report at the end of the semester.

The evaluation criteria comprise the evolution of the three iterations of ITRB. In this evolution the students have to develop a report and a concept map, both for the research question. The research question is evaluated in terms of its consistency and coherence. According to these criteria the concept map and the report are evaluated in each one of the iterations.

It can be seen that the production process of the ITRB is dynamic and the construction of the concept maps is iterative in these activities. These iterations were designed so the concept maps would work as a strategy to facilitate the production of the ITRB. Specifically, the concept maps are a tool for:

- learning the technique of representing a knowledge that has been read – analysis of technical articles
- reflecting an acquired knowledge in a specific issue – approach to the research inquiry
- organizing information and synthesizing the acquired knowledge
- evaluating the learning process of a student in a specific issue

Figure 4 shows the relation between the activities that involves the production of the ITRB and the use of concept maps as a tool for supporting the ITRB production process.

3 The study case

Throughout the year 2007, 660 engineering students (in the second year of their careers) took PESO course and, consequently, participated in the production of ITRB and concept maps as support to this process. In order to evaluate the achievement of the proposed objectives (Figure 4) two variables were taken into account: perception and performance. Next, we explain each one of the measuring instruments.

3.1 Students' Perception

Our interest consisted in evaluating the perception of the student in term of ease of use of the concept maps, as well as the utility of this tool. The "ease of use" was related to the ease to approach technical reports through concept maps. The utility was defined in function of the concept maps usefulness for:

- understanding the proposal of the authors
- the main posing of the chosen inquiry
- the choice of key concepts (general and particular ones) for solving the inquiry
- finding relation between the key concepts
- the coherence between the proposals of the authors and the answer to the research inquiry
- validating the consistency between the technical report and the research inquiry

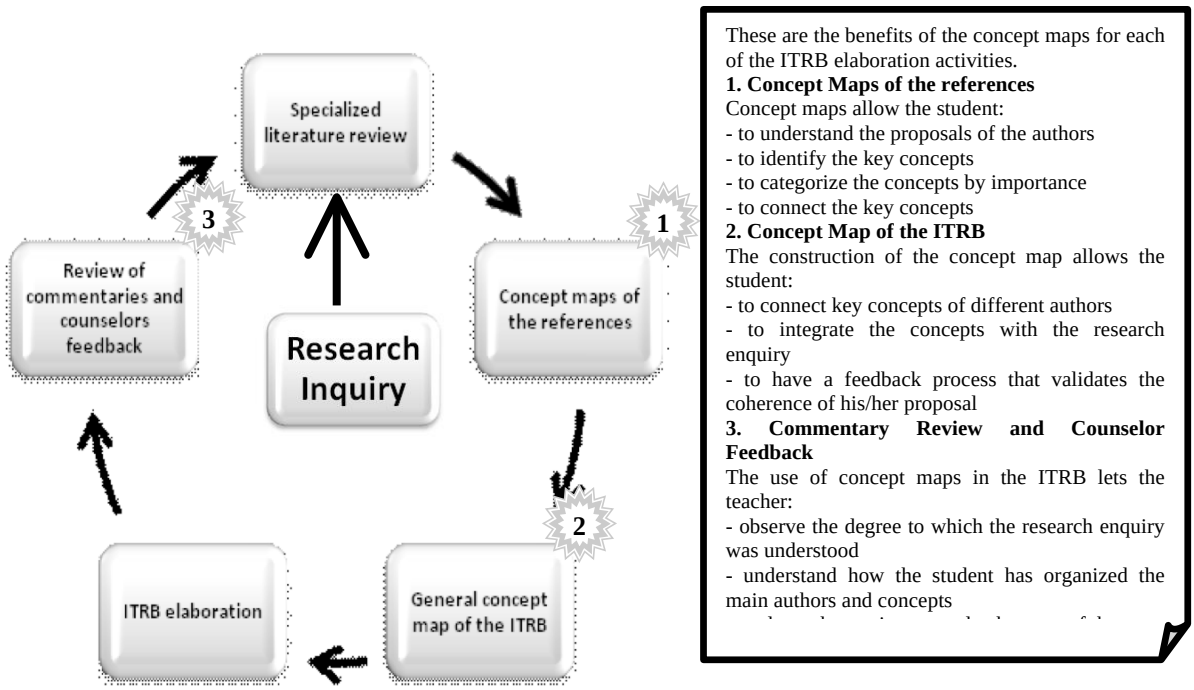

Figure 4. The ITRB elaboration process and its relation with the use of concept maps.

In order to evaluate these perception variables a survey was applied during March 2008. The survey was sent by e-mail to all the PESO students of 2007 (660). The rate of response was 28%. The results, questions and rate of response are shown in Chart 1.

The first six questions were intended to evaluate the perception that the students have regarding the utility of the concept maps, whether it is in terms of representing a text (question 1), reflecting acquired knowledge related to a specific issue (questions 2, 3 and 4), information organization and knowledge synthesis (questions 5 and 6). The results obtained show that the students perceive that the concept map is useful to assist with the production process of industrial engineering technical reports, taking into account each one of the described purposes.

Question 7 related to the ease of use of the concept maps tool. Once again, a large percentage of students rated this aspect positively (67% rated it 4 or 5).

Questions 8 and 9 related to the perceptions of the students regarding the use of this tool in other contexts. A total of 76% of the students have used concept maps in other projects. Additionally, 91% of the students think that making concept maps is useful to approach common engineering problems.

Another factor that complements these perceptions is student opinion expressed in the university surveys at the end of the semester. The students evaluated the ITRB activity as a practical and useful process for the course. Some students even suggested that this process could be replicated in other courses or used in the final research project at the end of the industrial engineering course. Professorial staff also recognize concept maps as a useful tool, both for them and for the students (see Figure 4).

3.2 Students' Performance

Student performance was evaluated by the measurement of each delivery against the criteria described in section 2.3. It is important to observe that the iteration process of ITRB includes the evolution of the report and the concept maps about the research question. The measurement grades went from 1 to 5 (5 being "excellent"). Figure 5 shows the mean grade evolution of the ITRB for the 184 students who answered the electronic survey. It can be seen that the ITRB evolves in the three deliveries (significance difference of means with a p-value under 0,001, assuming equal variances).

Rank: 1= least useful, 5=most useful

Questions	1	2	3	4	5
1. The concept map of the ITRB was useful for understanding the proposals of an author in reference to the research enquiry's issue (concept map of the references)	5%	5%	26%	35%	29%
2. The concept map of the ITRB was useful for conceiving the main statement related to the research enquiry	3%	9%	21%	43%	24%
3. The concept map of the ITRB was useful for determining which were the key concepts leading to answer of the research enquiry	1%	5%	25%	36%	33%
4. The concept map of the ITRB was useful for finding relations between the key concepts of the authors in relation to the research enquiry	1%	8%	24%	33%	34%
5. The concept map of the ITRB was useful for achieving coherence in the relation between the authors and the research enquiry	3%	11%	23%	38%	26%
6. The concept map of the ITRB was useful for validating the consistency between the main statement, the relations between the authors' concepts and the research enquiry	2%	12%	19%	43%	25%

Rank: 1= least easy, 5=most easy

Question	1	2	3	4	5
7. The development of concept maps is an easy to use tool for the approach to technical reports	1%	8%	24%	38%	29%

"Yes" or "No" questions

Questions	YES	NO
8. Have you used concept maps in contexts different from the ITRB?	76%	24%
9. Do you think the production of concept maps for approaching common engineering problems is useful?	91%	9%

Chart 1. Survey on perceptions (utility and ease-of-use of the concept maps as support to the production of technical reports in engineering)

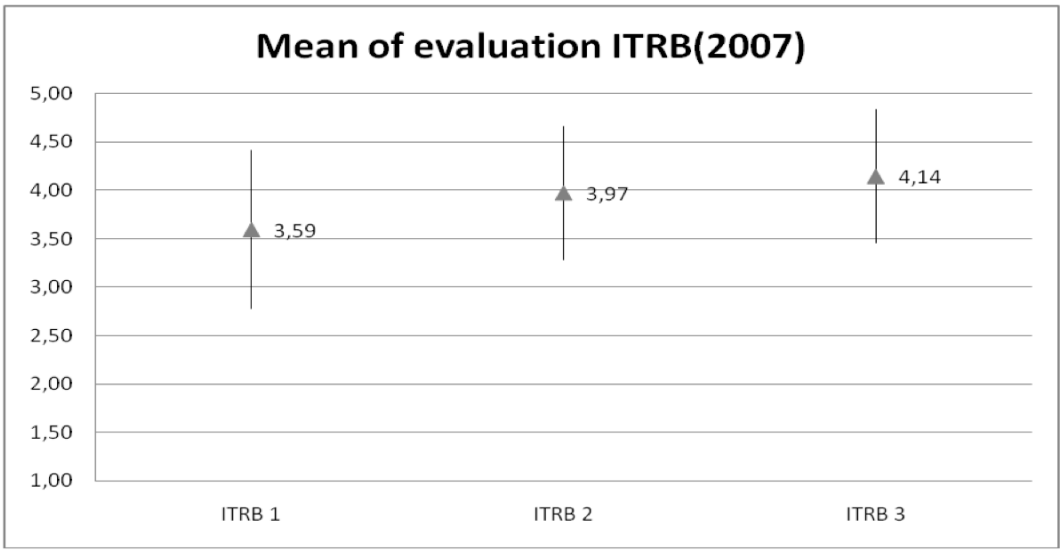

Figure 5. Mean and standard deviation obtained in the evaluation of the three deliveries of the ITRB.

One example of concept maps developed by the students in their ITRB is shown in Figure 6. In this concept map we can observe the improvement in the process applied to the research enquiry. For example, it evidences the inclusion of new concepts and relations, and the increment of these items through the deliveries. A particular analysis that could be developed in a future study relates to the following question: to what extent does this increase of the number of concepts and their coherence with the research question improve skills for solving industrial engineering problems?

4 Final Considerations

This work has shown the contribution made by the production of concept maps to the approach to common industrial engineering problems seen in the PESO course. Some examples of research enquiries were presented as well as the steps in constructing technical research documents. Some indicators regarding the ease-of-use and the utility of the concept maps, in the opinion of the PESO students of 2007, were presented, together with the students' performance in the ITRBs.

The main conclusions of the perception survey indicate that 67% of the students consider the concept maps a useful tool to elaborate their ITRBs; and 67% think this tool is easy to use. An interesting element that

generates research opportunities is the use of concept maps in other environments; as a matter of fact, over 70% of the students have used them afterwards in other learning environments. Additionally, the general student and teacher perceptions of the concept maps have been a useful tool to enhance the writing and reading skills of the students.

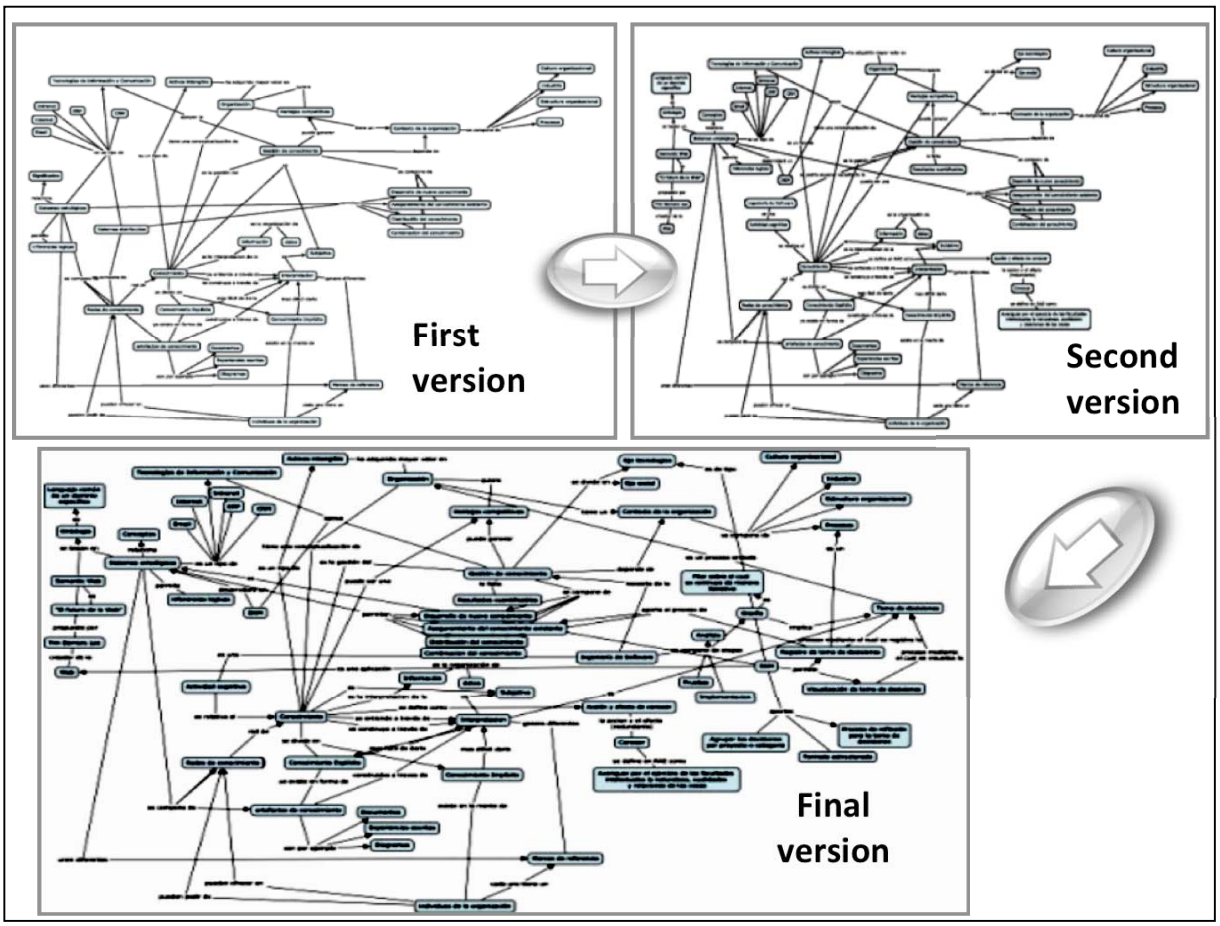

Figure 6. An example of a concept map developed by the students (Student: Jorge A. Quiroga, (jor-quir@uniandes.edu.co). Theme: How does the use of IT support the knowledge production in an organization? PESO 2007).

The method used in the ITRB (report and concept map) process is related to the proposal skills made by ABET (2003) and NAE (2004), specifically in terms of communication abilities and the identification, formulation and solution of engineering problems.

Impressed by the results of the concept maps used in PESO, some of the professorial staff of the Department of Industrial Engineering of Los Andes University have begun to use this tool in their courses. They and their students have also used concept maps in research projects.

Both the utility perception of the teaching staff and the results of the performance indicator of the students in the elaboration of the ITRB are evidence that the use of concept maps allows the students to integrate the concepts of several authors and to propose an answer to a research enquiry that simulates industrial engineering problems. Future works in this area include the following: (a) to explore and analyze how the number of concepts and connections evolve through the deliveries, and (b) to explore how this tool may be used in other aspects of the course (for example, in lectures and case studies).

5 Acknowledgments

This work was made possible thanks to the cooperation of the professorial staff and the students of the Systemic Thinking in Organizations course (PESO) of the Los Andes University Industrial Engineering Department.

References

ABET. (2003). Criteria for Accrediting Engineering Programs. Retrieved January 17 2008. Available in: http://www.abet.org/images/Criteria/E001%2004-05%20EAC%20Criteria%2011-20-03.pdf

Ashby, M. (2000). How to write a paper. Engineering Department, University of Cambridge, 5th Edition, Cambridge: UK.

Bransford, J. D. & Council, N. R. (eds.) (2000). How People Learn: Brain, Mind, Experience and School. Washington, D.C.: National Academy Press.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (2000). Assessing science understanding: A human constructivism view. San Diego: Academic Press.

National Academy of Engineering. (2004). The Engineer Of 2020: Visions Of Engineering In The New Century. The National Academies Press , 118.

Novak, J. D. (1990). Concept maps and vee diagrams: Two metacognitive tools for science and mathematics education. Instructional Science, 19 (1), 29-52.

Novak, J. D., & Cañas, A. J. (2006). La teoría subyacente a los mapas conceptuales y a como construirlos. Florida Institute for Human and Machine Cognition (IHMC), Retrieved January 17 2008. Available in: http://cmap.ihmc.us/Publications/ResearchPapers/TeoriaSubyacenteMapasConceptualeshq.pdf.

Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York: Cambridge University Press.