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Concept maps and the meaningful learning of science

Los mapas conceptuales y el aprendizaje significativo de la ciencia

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Abstract
The foundations of the *Meaningful Learning Theory* (MLT) were laid by David Ausubel. The MLT was highly valued by the contributions of Joseph Novak and D. B. Gowin. Unlike other learning theories, the MLT has an operational component, since there are some instruments based on it and with the meaningful learning facilitation as aim. These tools were designated *graphic organizers* by John Trowbridge and James Wandersee (2000, pp. 100-129). One of them is the *concept map* created by Novak to extract meanings from an amalgam of information, having currently many applications. The other one is the *Vee diagram* or *knowledge Vee*, also called *epistemological Vee* or *heuristic Vee*. It was created by Gowin, and is an excellent organizer, for example to unpack and make transparent the unclear information from an information source. Both instruments help us in processing and becoming conceptually transparent the information, to facilitate the cognitive process of new meanings construction. In this work, after a brief *introduction*, it will be developed the *epistemological* and *psychological grounds* of MLT, followed by a reference to *constructivist learning environments* facilitators of the meaningful learning, the characterization of *concept maps* and exemplification of its use in various applications that have proved to be very effective from the standpoint of meaningful learning.

Resumen
Los cimientos de la Teoría del Aprendizaje Significativo (TAS) fueron puestos por David Ausubel y fue valorado muy positivamente por las contribuciones de Joseph Novak y D.B.Gowin. A diferencia de otras teorías del aprendizaje, el TAS tiene un componente operativo, ya que en virtud del mismo, y teniendo como objetivo facilitar el aprendizaje significativo, se crearon instrumentos, que John Trowbridge y James Wandersee llaman organizadores gráficos guiados por la teoría (2000, pp. 100-129). Uno de ellos es el mapa conceptual, fue creado por Novak con lo propósito de extraer significados de una amalgama de información, teniendo actualmente muchas aplicaciones. La otra es la Uve del conocimiento, también llamada Uve epistemológica o Uve heurística y fue creada por Gowin, que es excelente, por ejemplo para desempacar y hacer transparente un contenido poco claro de una fuente de información. En el fondo, ambos nos ayudan a procesar y tornar conceptualmente transparente la información, para facilitarnos el proceso cognitivo de construcción de nuevos significados. En este trabajo, después de una breve introducción será desarrollada la base epistemológica y psicológica del TAS, una referencia a los entornos constructivistas de aprendizaje facilitadores del aprendizaje significativo, la caracterización de los mapas conceptuales y la ejemplificación de su uso en diversas aplicaciones que han demostrado ser muy eficaces desde el punto de vista del aprendizaje significativo.

Keywords
Meaningful learning; human constructivism; constructivist learning environment; graphic organizer; concept map.

Palabras clave
Aprendizaje significativo, el constructivismo humano, el medio ambiente constructivista del aprendizaje, organizadores gráficos, mapas conceptuales.

1. Introduction

It was in the early 80s I had the first contact with the semi behaviorist and the cognitivist theories of learning, including the theory of Ausubel.

In 1981, Joseph Novak was invited by the Portuguese Chemical Society to present in Lisbon his *concept maps*, which are graphic organizers guided by the MLT. Since then I never stopped to appreciate the merits of the MLT and I used concept maps with my high school students, later with University students and also with many teachers to whom I gave training. In 1992, I went to Cornell University, where I participated in a Seminar where Prof. Novak made me see the importance that also has the knowledge Vee, of Gowin, for the meaningful learning.

The current teaching must be based on *good epistemological*, *psychological* and *educational grounds*, which was not the case with traditional teaching. In the *traditional schools*, teachers used almost exclusively the exposition of the programmatic contents, with all the shortcomings that Ausubel points to this traditional expository teaching (Ausubel, 2003, p. 7). Such teaching is bad because the teacher uses prematurely "pure verbal techniques" and exposes, in a prolonged and often monotonous way, often scattered and not integrated contents, sometimes incoherent and arbitrary, therefore without logical meaning, having no account if students have adequate cognitive readiness to learn meaningfully. Furthermore, the traditional teacher uses a sporadic assessment, almost exclusively summative, when he must use a systematic and essentially formative assessment.

It is *impossible to change* this traditional behavior without *transform the epistemology* and, consequently, the ideas about the nature of scientific knowledge and the process of its construction (Bell and Pearson 1992, in Gil-Pérez, 2002).

The MLT, as well as the graphic organizers based on it (Trowbridge and Wandersee 2000, pp. 100 - 127), particularly the Novak's concept map and the Gowin's knowledge Vee, are cemented on what Novak called *human constructivism*. This is the focus of the next section.

2. The human constructivism

In the Preface of the book «*The Practice of Constructivism in Science Teaching*», published by the *American Association for the Advancement of Science*, we can read that "*there is widespread acceptance of constructivism*" that "*constructivism has become increasingly popular*" and that it represents a "*paradigm chance*" in science education (Matthews, 1998, p. 2).

But when we refer to constructivism is important to characterize *what kind of constructivism* is, because the word «constructivism» is *polysemic*, which originated that *several variants of constructivism* arose, contextual, dialectical, empiricist, rationalist, pragmatist, personal (based on Piaget), social (based on Vygotsky), radical (of von Glasersfeld), sociological (based on the Strong Program of Edinburgh School), and so on (Matthews, 1992, p. 34; Bickhard, 1998, p. 104-108, von Glasersfeld, 1996, Nola, 1998, p. 33, Kragh, 1998, p. 127).

Some *radical and sociological constructivist ideas* have been strongly criticized, for example, ideas of the so-called «*Strong Program of Edinburgh School*» and ideas of the «Frankfurt School», that the science historian Helge Kragh consider in line with the *historic attacks on Science* (Kragh, 1998, p. 126). Due to psychological idealism, anti-realism, anti-objectivism and skepticism of many constructivist ideas, many thinkers have rejected the constructivism. But there are several authors, for example Bickhard (1998), who consider the rejection of constructivism a wrong position. John Staver claims (1998, p. 501) that even many critics of constructivism have recognized their beneficial contributions for education. I believe, based on many «*science studies*» and others about the nature of human cognition, also based on philosophers like Johannes Hessen (1987), who was professor at the University of Cologne in the last century, and in epistemologists like Popper, for example, that *constructivism does not must fall into anti-realism, anti-objectivism, relativism and skepticism* when do not defend the strong objectivity of science and naive realism that some scientists have revealed. For example, none of the many thinkers who collaborated on the book "*A Ciência tal qual se faz*" (Gil, 1999) deny some intrinsic rationality and objectivity to the science.
In accordance with Niaz et al. (2003, p. 787) and other authors according to which it is not possible to implement a coherent and authentic constructivist pedagogy without an underlying constructivist

epistemology, well characterized by its epistemological, sociological, psychological and educational facets, it is important to ask: what is then the constructivism that underlies the MLT and the creation of their graphic organizers?

The constructivism that underlies the MLT is the *human constructivism* of Novak, and the first contact I had with it was through a paper he presented at the Fourth North American Conference on Personal Construct Psychology, San Antonio, Texas, in 1990. In this paper Novak says: "*Human Constructivism, as I have tried to describe it, is an effort to integrate the psychology of human learning and the epistemology of knowledge production*" (Novak, 1990, p.15). On the other hand, Mintzes and Wandersee consider human constructivism as "*a vision of creating meanings that encompasses a theory of learning and an epistemology of knowledge construction*" (2000, p. 58). This theory they refer is the *Meaningful Learning Theory* and the *epistemology* behind it is *constructive* and *humanistic*, based largely on Gowin and Novak ideas.
Such as any good theory, *human constructivism* is based on broad principles (Novak, 1990, 2000; Gowin, 1990; Mintzes e Wandersee, 2000):

- Human beings have a capacity for meaning making that can be optimized.
- Thinking, feeling and acting contribute together to change the meaning of the human experience.
- Although there is an idiosyncrasy in individual concept structures, there is sufficient commonality and isomorphism in individual meanings so that the dialogue is possible and sharing, changing and enriching meanings is possible.
- The education must promote the construction of shared meanings.
- The shared meanings can be facilitated by the active intervention of well-prepared teachers.
- The scientific and artistic production, at the highest level, is a highly creative and original construction of new meanings and therefore of highly meaningful learning, the ideal where must be pointed the learning at schools.

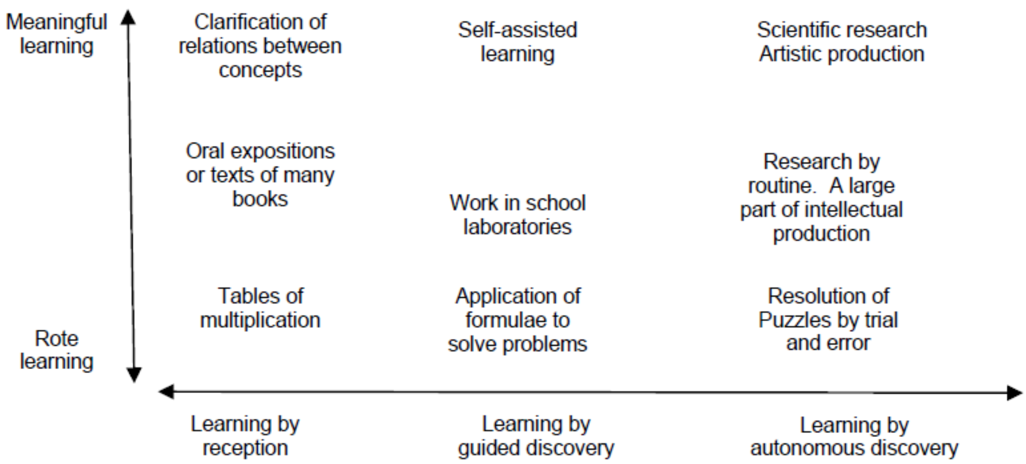

Image 1. Two dimensions of learning (adapted from Ausubel, Novak e Hanesian, 1980, p. 21, Novak e Gowin, 1999, p. 24 and Novak, 2000, p. 28).

In the preface of the book «*Ensinando ciência para a compreensão – uma visão construtivista*» (2000, p. 17), coordinated by Joel Mintzes, James Wandersee and Joseph Novak, we can read the following:

> "In contrast to the notion of radical and social constructivism, the human constructivism takes a moderate position about the nature of science. On one hand considers the opinions of the logical positivists intellectually indefensible; on another hand, considers that many constructivists created a relativist mental world that ends up destroying itself. Prefers, instead, a view of science that acknowledges an external and knowable world, but that largely depends on an intellectually demanding struggle to build heuristically strong explanations through extended periods of interaction with objects, facts and other individuals".

The *moderate position* that the *human constructivism* has about the nature of knowledge is due to its *surpassing character* of the great *historical antitheses* that emerged in the philosophy of knowledge. Thus, the human constructivism considers that knowledge, whatever it may be, is constructed based on a *complex interaction* between two major components, one *conceptual* and another *methodological* and *experimental*, and that this interaction nvolves several epistemological blocks. It is very well translated in the knowledge Vee, epistemological Vee, heuristic Vee, of Gowin:

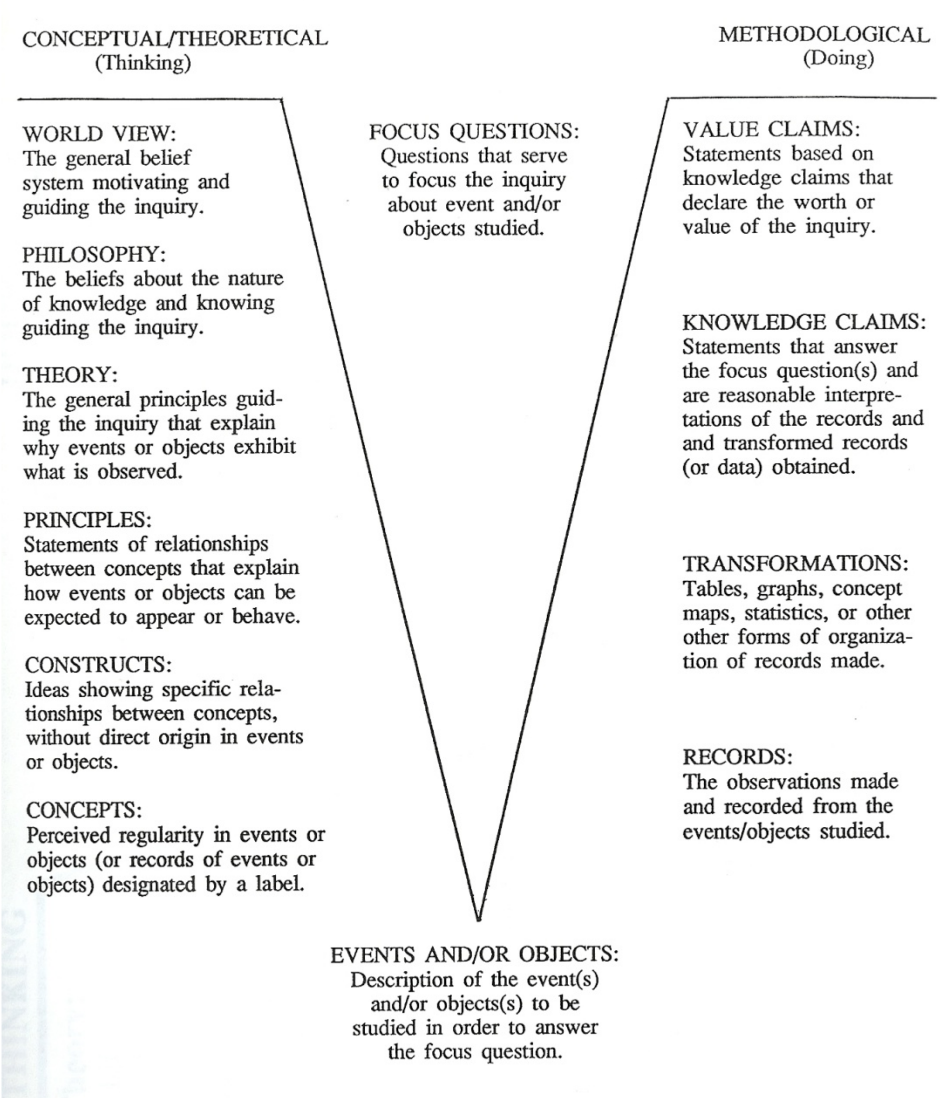

Image 2. The knowledge Vee, heuristic Vee, or epistemological Vee, of Gowin, in its general form

In *psychological terms*, the human constructivism considers the knowledge *assimilation* as a *personal* and *idiosyncratic* process, yet deeply *influenced by social contexts*, real or virtually lived. In this process, the *subject* behaves as a *multifaceted being* where *thinkings*, *feelings* and *actions* combine to give *meaning* to the life *experience*. The subject is immersed in a world of *information*, but this *is not knowledge in itself*. It is necessary make interact and integrate the information into the cognitive structure. *Language* is *fundamental* in coding, shaping and acquiring new meanings and also contributes to the assimilation of knowledge by each individual as an idiosyncratic process.
The *human constructivism* has *educational implications* that must be highlighted here:

- The fact that the student has to be considered the structuring element of his learning.
- The fact that the ideas can make sense for a student without being accepted by another student and the teacher.

- The idea that students should be involved in a process of heuristic and personal search but also in a fruitful interaction with other students and the teacher.
- The importance that the student's preconceptions, and particularly their misconceptions, have in their learning.
- The essential role of the teacher, that should intervene (exposing ideas when and only when is necessary) to provide the students with adequate evidence and provide them with the concepts and theoretical models of science.
- The importance of providing students with a humanistic vision of science, to assert its fallibility, as everything that is produced by human beings.
- The importance of dialogue and debate of ideas in the classroom. In the words of Novak and Gowin (1999, p. 37) "*learn the meaning of a given knowledge implies dialogue, exchange, share, and sometimes make compromises.*" Share yes, but not learning. *Learning* is an activity that *can not be shared*, it is rather a matter of individual responsibility. On the contrary, the *meanings can be shared*, discussed, negotiated and subject to consensus (*idem*).

3. Constructivist learning environments

It was in the 90s that we began to feel the effect of constructivist ideas in the research about classroom environments (Valadares, 2001). An instrument, named *Constructivist Learning Environment Survey* – CLES, was created by Taylor and Fraser (1991), to assess the perceptions of teachers and students about some *dimensions* that were considered *important in classroom environments* (Sebela 2003). These dimensions are:

- *Personal Relevance* – existence of a relation of the taught subjects with the daily experiences of students.
- *Uncertainty* - highlight the importance of beliefs, theories, experiences and values in the scientific research.
- *Shared Control* - control of the environment shared by all, based on an ongoing and formative assessment.
- *Student Negotiation* - dialogue and sharing of ideas among students with an emphasis on peer assessment.
- *Critical Voice* - nothing and no one is above constructive criticism. (*idem*)

A new version of this instrument was created (Taylor, Fraser and White, 1994) and also other similar instruments. Many researches have been made to validate them and to draw conclusions (Cannon, 1997, for example). These and other researches that were made in the ambit of a *Science Teaching Master* (I created at the Open University of Portugal, in 1997) show that the constructivist learning environments can significantly improve student learning (Soares, Valadares and Malheiro, 2006).

To fundament in a more objective way these *constructivist learning environments*, I go to detach three important aspects: the teacher role; the learner role; the educative relationships that must be established (Valadares, 2007).

Beginning by the *teacher***,** he will have to know and to have in account, permanently, the points of view of the pupils, their ideas and conceptions, to provide adequate activities to defy the assumptions of the students, to place problems whose relevance is recognized by them, to conceive the strategies on the basis of ample and inclusive initial concepts, and to assess continuously the learning of the students in a perspective as "*formatrice*" as possible. The so-called "*formatrice assessmen*" is a very elaborated kind of formative assessment completely integrated in the teaching-learning process that was proposed by a group of researchers of the "Academie d' Aix-Marseille", having as finality to be *as pro-active as possible*, contributing to open and facilitate the path of students, foreseeing their own difficulties in each subject.

The *learner* has to have *active engagement* in the learning (including the learning of group colleagues), should be *open to criticism*, and *inquirer* in permanent search of knowledge, should be *intentional* in what concerns to the search of answers to the challenges that are placed to him, to *know dialogize* with colleagues and teacher, should be *reflexive*, to think about what he made and be *amplifying*, in order to enlarge his learning to the world outside the school.

Finally, teacher and students must try to establish *good and strong pedagogical relationships*, based on good *interpersonal relations*, being essential that could be established a *climate of cooperation* with the greatest attention to the *students representations* and to the meta representations or representations of the representations (typical example: what he thinks about what I think about him).

Based on Brooks and Brooks (1997), with personal adaptations, I finished this section comparing the constructivist learning environments with the traditional learning environments.

Traditional learning environments	Constructivist learning environments
- Curriculum is presented in parts, integrated in a whole, emphasizing basic skills. - Curriculum is rigidly followed, without to have in account the meaningful learning. - Classroom activities are based on textbooks and workbooks. - Students are considered "*tabulas rasas*" onto which information is recorded. - Teachers generally are limited to disseminate information to students, without caring about their learning environments. - Teachers seek only the correct answers to validate students' learning, and depreciate answers that reflect their mental models. - Assessment of students learning is viewed as separate from teaching, is episodic and essentially sumative, almost exclusively based on tests. - Students work primarily alone.	- Curriculum is presented as a whole, showing the general concepts, and then broken into parts. - Curriculum is followed so that the meaningful learning is facilitated - Classroom activities are based on primary sources and chosen materials. - Students are viewed as representational and computational beings. - Teachers generally interact and share ideas with students, caring about their learning environments. - Teachers seek the students' points of view in order to understand their mental models, to explore these to better learning. - Assessment of students learning is multifaceted, integrated into the teaching, and based on the systematic observation of the students activities and works. - Students work primarily in groups but also individually.

A look at learning environments (adapted of Brooks and Brooks)

4. Some essential ideas about the Meaningful Learning Theory

The MLT dates back to 1963 when David Ausubel published a work entitled "*The Psychology of Meaningful Verbal Learning*". It is a theory about human learning, based on the *study of the mechanisms* through which the *acquisition* and *retention* of a *great quantity of meanings* is processed (Ausubel, Novak & Hanesian 1980). It is a *constructivist theory*, as is based on the principle that it is the human being, as an organism, which is constructing and managing the product of their own learning.

The key concept of the MLT is *meaningful learning*. This important concept, as Ausubel conceived it, represents a process through which *new knowledge is related to the cognitive structure of the learner*. This is a process which is *substantive* (it is the 'substance' of the concept that is related), and thus occurs in a non-literal way. And is a *not arbitrary* process, since new knowledge is precisely related with some adequate and relevant contents which are present in the cognitive structure, called *subsumers*, *integrating ideas* or *anchor-ideas*.

The term anchor-idea (or only *anchor*) is the least suitable of the three presented above, because the meaningful learning process is not a simple anchorage, a simple union between the new knowledge and the knowledge that learner already has.

As far as this process takes place, when the new content goes acquiring meaning for the subject, a transformation of the subsumers of cognitive structure goes occurring. In the *meaningful assimilation*, new knowledge interacts with a subsumer, this is modified, and the new knowledge acquires a personal meaning, as illustrated in the following scheme:

S + I → S'I'

Subsumer new information

It is the presence of relevant concepts and propositions, clear and inclusive ideas in the mind of the learner, that will provide meaning to new knowledge in interaction with these ideas. Meaningful learning is this *cognitive mechanism*, but also is the *product* of the same, that is, the attribution of meaning to new information, accompanied by a modification and enrichment of the subsumer, which thus becomes more explanatory and potentially richer to underpin future learning. It is therefore a process simultaneously *constructive* and *reconstructive*.

In order to have *meaningful learning* two *conditions* must be fulfilled:

- The confrontation of the learner with a *potentially meaningful content*, which requires that:
  - this content has *logical meaning*, what means that it is conceptually consistent to the point of being potentially linkable to the cognitive structure of the learner, in a substantive and no-arbitrary process;
  - - there are *appropriate subsumers* in the learner's cognitive structure that enable interaction with that new content.
- That the learner has a *potentially meaningful attitude*, that is, a willingness to learn meaningfully.

According to Ausubel, what we learn are words or other symbols, concepts and propositions. Therefore, with regard to the *object* that is *learned*, the *meaningful learning* can be classified into: *representational*; *conceptual*, and *propositional*.

The representational learning, which consists of associating labels to things, occurs since an early age and naturally leads to meaningful learning of concepts, without which it is impossible to learn meaningfully propositions, since these depend on the meanings of the concepts involved in them. The *concepts* are therefore the *focus* of the meaningful learning, and with them we think and communicate.

When the criterion used is the *hierarchical organization* of cognitive structure, meaningful learning can be of three types: *subordinate*, *superordinate* or *combinatory*.

Thus, through the assimilation process, the subsumers go increasingly assimilating concepts and propositions and, consequently, broadening its scope. This process is called *progressive differentiation*, and the meaningful learning that occurs by this mechanism is called *subordinate learning*.

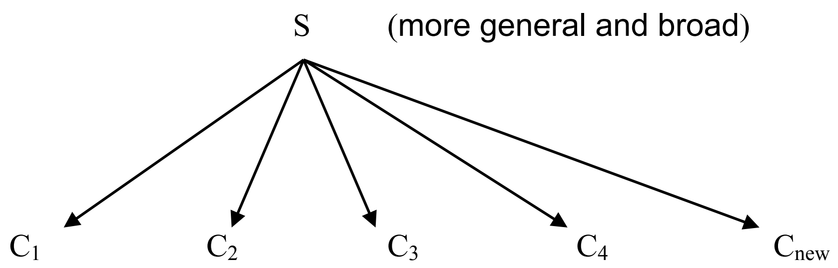

Image 3. In the subordinate learning the new concept or proposition is subordinated to pre-existing subsumers that are more general and broad.

But at the same time that the concepts are differentiated and become enriched, cognitive relations between concepts are going increasingly found. When these bridges between cognitive concepts, sufficiently differentiated, are established, that is, when occurs what Ausubel named *integrative reconciliation*, more general and broad concepts called *superordinate concepts* may result. When they are constructed, what occurs is called a *superordinate learning*.

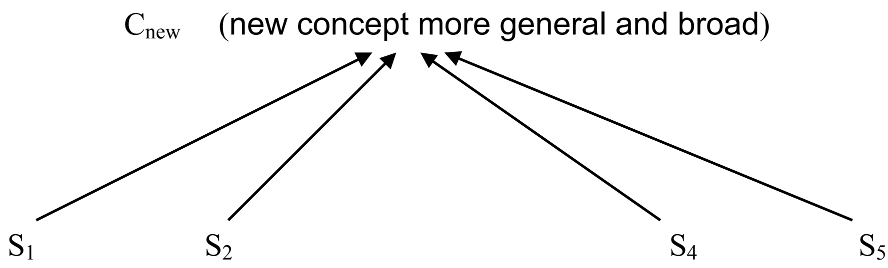

Image 4. In the superordinate learning the new concept or proposition originated is more general and broad than the pre-existing subsumers.

But it can also occur the *combinatorial learning*, in which new concepts are neither assimilated to subsume the former, as happens in the superordinate learning, nor are subsumed by them as happens in the subordinate learning.

We learn meaningfully by combining these systematic mechanisms: *progressive differentiation* of more general and comprehensive concepts, that increasingly are becoming more general, broad and richer, integrative reconciliation between concepts already sufficiently specified and differentiated to yield more general concepts and processes by which new ideas are linked to ideas of the cognitive structure that are neither higher nor lower in the hierarchy, for example by analogies. These mechanisms have implications on how ideas should be taught to the students and, in this regard, Ausubel says (2003, p. 24):

"Educational psychologists tend to divide, unpredictably, the order of presentation, 'descending' or 'ascending', and subsequent organization in cognitive structure. In general, neobehaviorist psychologists have favored the ascending order and constructivists the descending order."

Whilst Ausubel believes that one should start with general ideas, which will be gradually differentiated, also appreciates the existence of another mechanism with upward direction: the *integrative reconciliation*. The subject who learns meaningfully goes of the general to the particular and vice versa, in a process that introduce the new information in a hierarchized cognitive structure, systematizing it in an organized manner

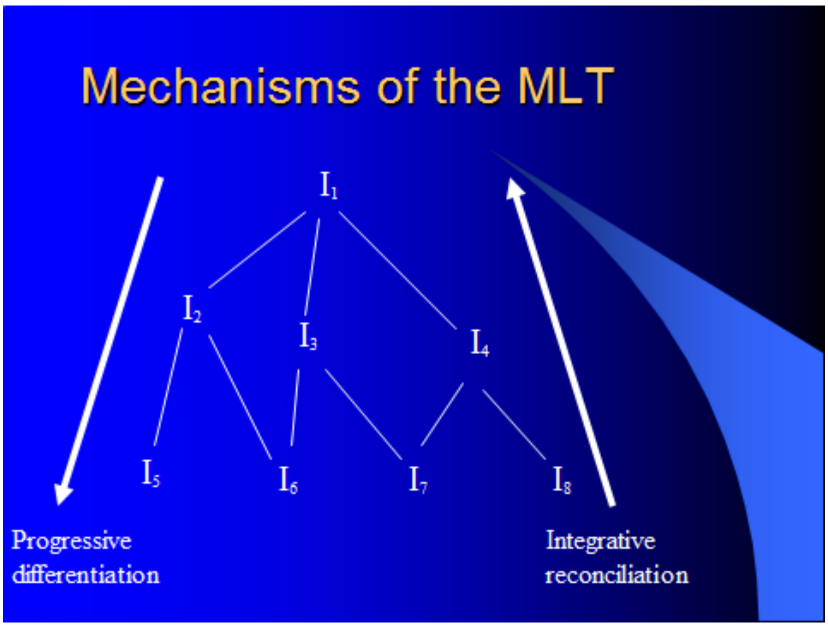

Image 5. In the meaningful learning, concepts go being linked in descending order and in ascending order

How not always, at any given stage of a student learning, he has the appropriate subsumers to learn meaningfully a "particular sphere of knowledge," then a way to facilitate learning and retention in these circumstances is "introduce appropriate subsumers up and make them part of the existing cognitive structure before the presentation of the learning task" (Ausubel, 2003, p. 65).

The concept of *meaningful learning* is also the *central concept* of the *Theory of Education* of Joseph Novak (1997). If Ausubel had already conceived the idea of the important role that the learner' cognitive structure has is in the *meaningful learning* process, Novak developed this idea making this fundamental concept less strictly cognitivist and *more humanistic*, considering the *transdimensional nature of the learner*, which like any other human being, *thinks*, *feels* and *acts*.

This human constructivist view, of Novak, in which the student is not seen as a thinking machine, but as a human being whose intellectual dimension is closely linked to other dimensions, goes in the same direction that the modern sciences and technologies of cognition defend. It is enough to remember the well-known work of António Damasio, «O Erro de Descartes», where this neurobiologist writes the following words (Damasio, 1995, p. 15):

"The lower levels of the reason neurological building are the same that regulate the process of emotions and feelings and even the bodily functions necessary for the survival of the organism. In turn, these lower levels maintain direct and mutual relationships with virtually every organ in the body, thus placing the body directly in the chain of the operations giving rise to the performances of the highest level of reason, decision making, and by extension, social behaviour and creative capacity. All these aspects, emotion, feeling, and biological regulation play a role in human reason. The orders of the lower level of our organism are part of the same circuit that ensures the superior level of reason."

Pretending that science education leads to a rich, substantive, not literal, learning of concepts, laws and scientific theories, able to enhance students to solve various scientific problems, the human mind trans dimensionality should be taken into account (Fernandes, 2000, Gardner, 1994), therefore the planning of teaching must use different media, different strategies and different ways of expression.

Joseph Novak consider very important that students reveal their cognitive structure, that «negotiate» and exchange meanings with each other and with the teacher, and that meaningful learning mechanisms are applied in schools. These are the reasons why he created his well-known but underused metacognitive tool called *concept map*. This work ends with this graphic organizer based on the MLT and with a handful of excellent applications that this organizer can have on education.

5. The concept map and the facilitation of meaningful learning

In a generic way, a *concept map* is a diagram that indicates relationships between concepts. In the context of MLT, it is a hierarchical diagram that seeks to reflect the conceptual organization of a knowledge body or part of it, as this organization is understood by whoever builds the map. Its existence derives from the conceptual structure of a given knowledge body, so it corresponds to a set of concepts linked together by linking words to form up meaningful claims.

The following picture shows a simplified model to construct a concept map in order to respect the *principles of meaningful learning*, specifically the principles of *progressive differentiation* and *integrative reconciliation* of concepts.

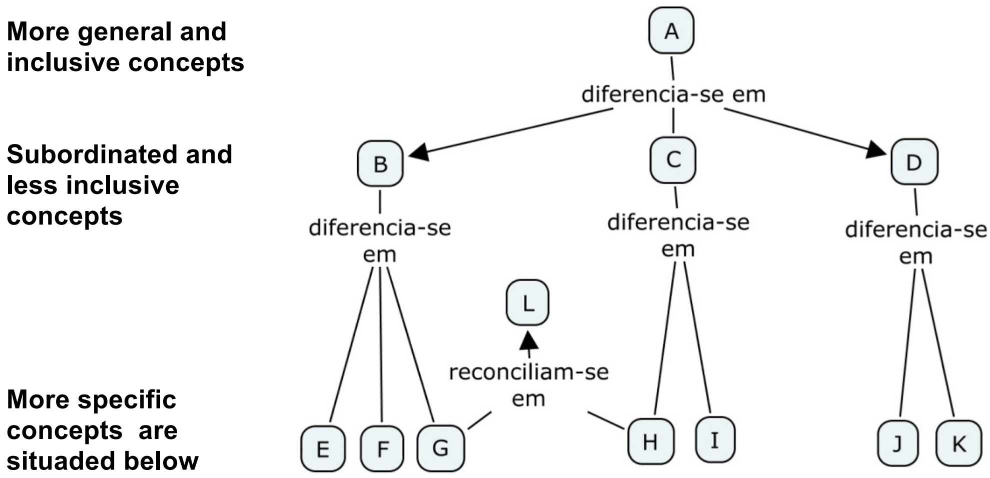

Image 6. A concept map model that respects the principles of progressive differentiation and integrative reconciliation

It is clear a *hierarchy of concepts*, and a *progressive differentiation* from the more general and inclusive concept, A, until to the most specific, E, F, etc. The examples, being in general concrete, are sent to the base of the map. Lines joining concepts traduce relationships between them, including cross relationships. It is also possible see an *integrative reconciliation* of concepts G and H that were subsumed in a more general concept than them: the concept L. This hierarchical arrangement according to the vertical direction, from top to bottom, is the most common, but it is perfectly conventional. Consider the following example

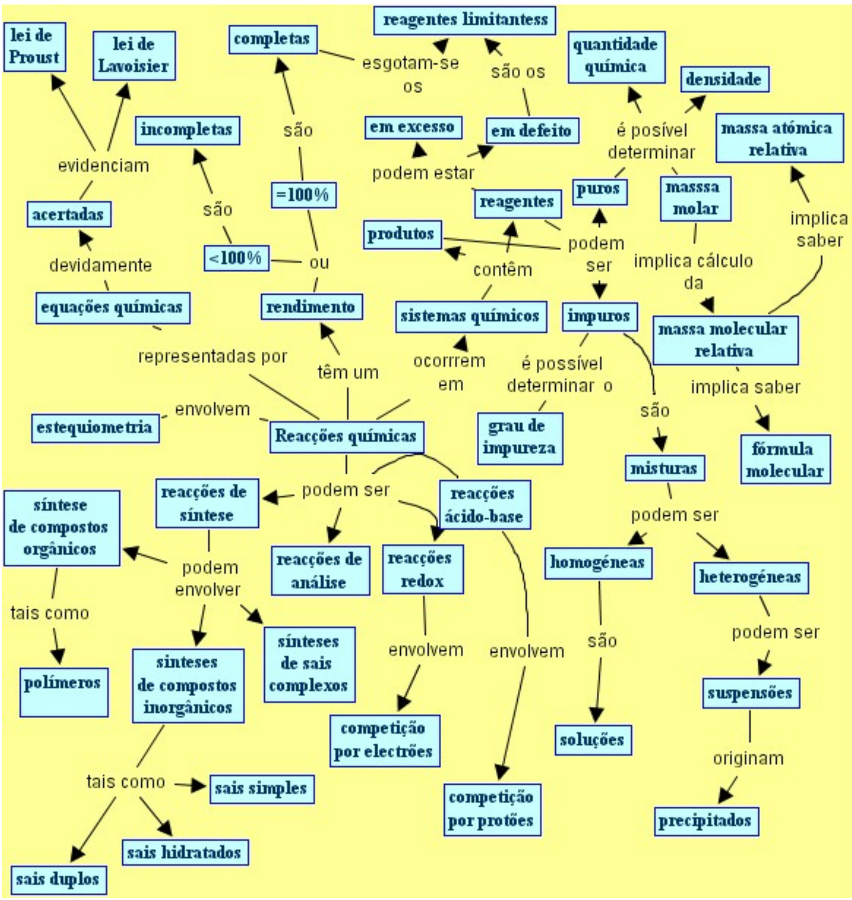

Image 7. *A concept map about chemical reactions (Gouveia e Valadares, 2005).*

This map is hierarchized from the middle to the periphery. The concept more general and inclusive is «chemical reactions» and is differentiated in various branches toward the periphery. The concept map has many applications as we see from the following examples.

5.1. The use of concept maps to "negotiate meanings"

More than the value of a concept map itself, always limited, since there is a more or less crude representation of a conceptual framework, what is fundamental is the mode how it shows the meanings that its builder has, and permit negotiate them with others. Here is an example. An experienced Physics teacher knows that many students, even with several years of study of this discipline, have absolutist conceptions of space and time, which difficult the understanding of Einstein's theory of relativity. The student's cognitive structure, heavily influenced by spontaneous thought based on daily life, where the bodies are moving at low speeds, and by the Newtonian physics that was built for such bodies, may be represented by a concept map like the following:

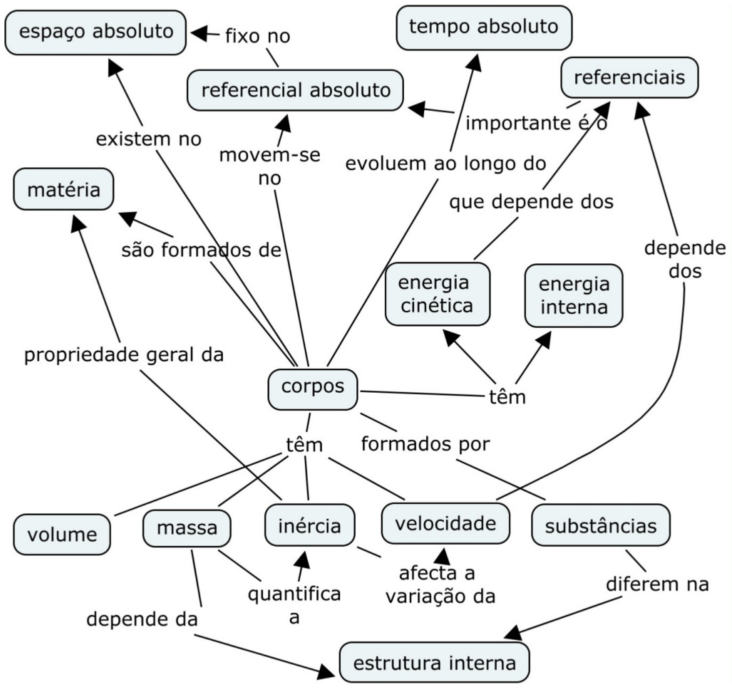

Image 8. Concept map that reveals the classical and absolutist conceptions on space, time and mass

Based on a map like this, it is possible for the teacher, through appropriate questions, elicit a fruitful discussion that will lead to a relativistic representation of space and time and to a more meaningful and correct concept of mass. I am thinking of questions such as: Speed affects internal structure? Inertia that is quantified by mass depends on the speed? What influences the internal structure? What is the reason why, when the speed of a particle, higher than 10 % of the speed of light in vacuum, is increasing, actuated by a constant force, is necessary to wait increasing time to obtain the same increase of velocity? Etc.

In fact, at speeds higher than 10% of the speed of light in vacuum, it is no longer possible to admit the separation between an absolute space and an absolute time, because the phenomena occur in a four-dimensional space-time referential. On the other hand, it is essential to discuss what means that a particle at increasing velocity and subjected to a constant force, requires more and more time to experience a similar increase in speed. It will be because the particle structure change? Its inertia, and therefore its mass, increases with speed? Or this is a consequence of the relativistic time dilatation?

The teacher may lead students to change the concept map as he is teaching the concepts of relativistic space, time and mass, or alternatively, he can put a new base map and proportionate a fruitful discussion of these concepts based on it.

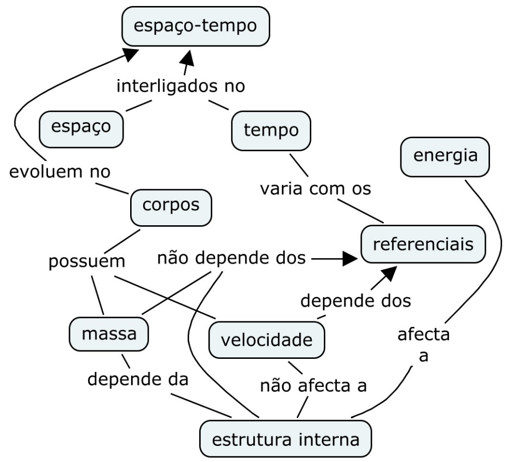

Image 9. Concept map that can provide the basis for "negotiation" of the meanings ofspace, time and mass at high speeds

5.2. The use of concept maps as assessment tools

Concept maps show to be very useful not only as an aid in determining the student's prior knowledge, but also to investigate changes in the cognitive structure produced by teaching. Thus it becomes possible to obtain information that can serve as feedback for teaching and the curriculum. Obviously, this is not an accurate and complete representation of the student' prior knowledge, but still allows the detection of *misconceptions* and other *conceptual blockages* to learning whose detection is useful for the further conceptual enrichment of the student.

The following concept map was built by a student to the teacher's request (the author of this work), after having completed an excellent experimental work, where determined a good value for the *mechanical equivalent of heat* and after having made a report of good quality. The concept map constructed by the learner allowed to detect conceptual difficulties and misconceptions that the work and the good report did not permit identify.

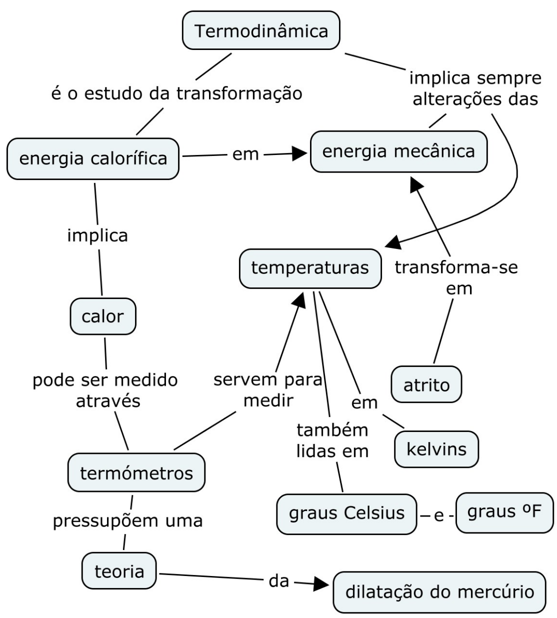

Image 10. Concept map constructed by a student after an experimental work on Thermodynamics; note the conceptual confusion between heat and temperature and confused ideas about heat

5.3. The use of concept maps in the curriculum area

Concept maps can be constructed for the content of a lesson, a discipline, a set of disciplines or an entire educational program. Everything depends on the generality or specificity and level of inclusivity of the concepts that are on the map. Broad and integrator concepts can serve as a basis for planning a curriculum of a particular course, while more specific concepts, little inclusive, can guide the selection of materials and teaching activities. Good curriculum planning involves a careful analysis of the concepts which are central to the understanding of the discipline, or part of the discipline, that is being considered. Concept maps can be extremely useful in this task.

The following concept map was constructed by the author of this work to guide the content development of a course on teaching models.

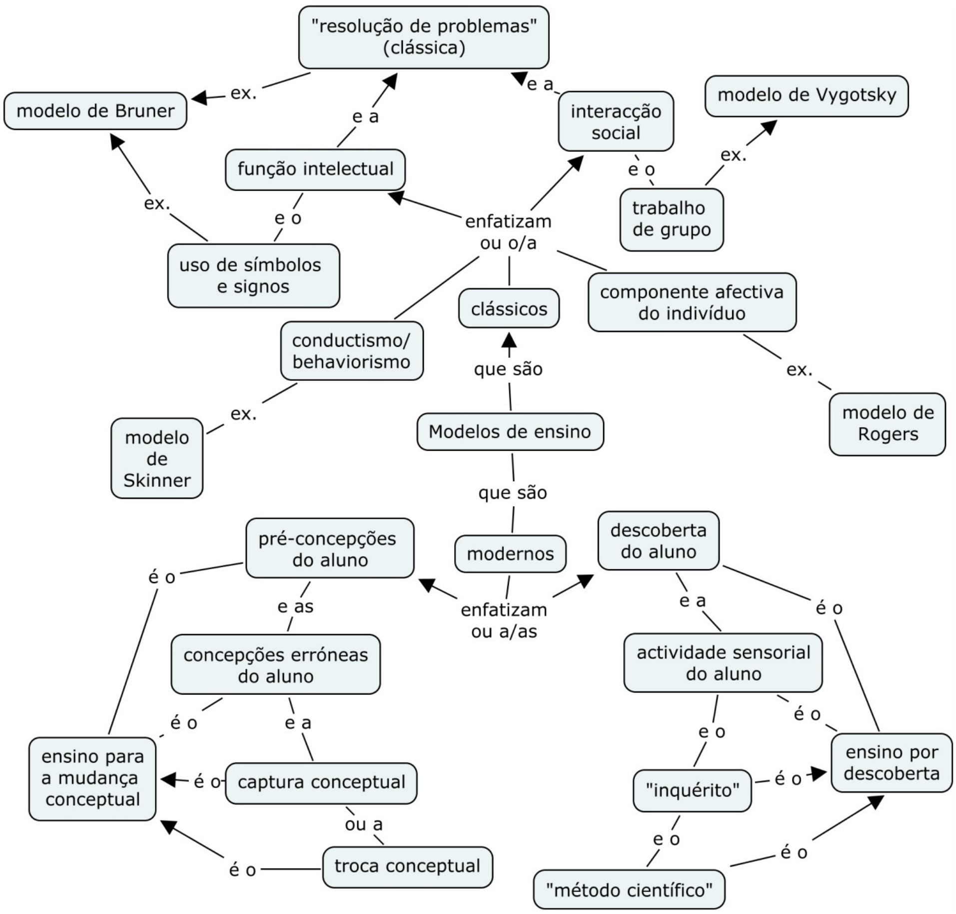

Image . A concept map constructed to guide the content development of a course on teaching models

6. Conclusion

The concept map, of Joseph Novak, is a graphic organizer that allows us to represent the conceptual framework of a knowledge area or how the concepts are connected and organized in the cognitive structure of who builds it. Although requiring some care in implementation, and many times requires initially a lot of time in its good construction and exploration, this instrument has immense utility in learning, teaching and assessment, particularly in a formative perspective. It is an instrument which facilitates meaningful learning of knowledge, as is based on the mechanisms of this kind of learning, and has many applications, some of which have been mentioned here, because it facilitates the structuring and clarification of any conceptual framework that becomes easier potentially meaningful. The correct use of concept maps should take place in a constructivist learning environment that was characterized here, and this instrument also may contribute to this kind of environment that is fruitful to the negotiation and sharing of ideas facilitator of the meaningful learning. In fact, such an environment stimulates the metacognition, promote the co-responsibility of students and contributes to positive interdependence between them, in favor of increasing the average yield of all of them.

In order these instruments can be explored to facilitate meaningful learning, it is necessary to know the ideas that permit use them correctly, otherwise we run the risk of the concept maps stimulate memory learning.

7. References

Ausubel, D.; Novak, J.; Hanesian, H. (1980). *Psicologia Educacional*. Rio de Janeiro: Ed. Interamericana.

Ausubel, D. (2003). *Aquisição e Retenção de Conhecimentos: Uma Perspectiva Cognitiva*. Lisboa: Plátano Edições Técnicas.

Bickhard, M. (1998). Constructivisms and Relativisms: A Shopper's Guide. In Michael Matthews (Ed.), *Constructivism in Science Education – A Philosophical Examination* (pp. 99-112) . Dordrecht: Kluwer Academic Publishers.

Brooks, J. ; Brooks, M. (1997). *Construtivismop em Sala de Aula.* Porto Alegre: Artes Médicas.

Cannon, J. (1997) The Constructivist Learning Environment Survey may help halt student exodus from college science courses: Comparing students' preferences and perceptions of constructivist-style teaching environment. *Journal of College Science Teaching*, Sept/Oct.

Damásio, A. (1995). *O Erro de Descartes, Emoção, razão e cérebro humano*. Lisboa: Publicações Europa América.

Fernandes, J. (2000). *Paradigma da educação da Globalidade e da Complexidade para a esperança e felicidade dos seres humanos*. Lisboa. Plátano Edições Técnicas.

Gardner, H. (1994). *Estruturas da mente – A Teoria das Inteligências Múltiplas*. Porto Alegre: Editora Artes Médicas Sul.

Gil, F. (1999). A ciência tal qual se faz e o problema da objectividade. In F. Gil (Coord). *A ciência tal qual se faz* (pp. 9-29). Lisboa: Edições João Sá da Costa.

Gil Pérez, D. (2002). La situación de la educación cientifica: problemas, avances y nuevas necesidades**.** In *Actas do VII Encontro Nacional sobre Educação em Ciencias*. Faro: ESE-Universidade do Algarve.

Gowin D. B. (1990). *Educating*, 2nd ed. Ithaca, N.I: Cornell University Press.

Hessen, J. (1987). *Teoria do Conhecimento*. Coimbra: Arménio Amado Editora.

Kragh, H. (1998). Social Constructivism, the Gospel of Science, and the Teaching of Physics. In Michael Matthews (Ed.), *Constructivism in Science Education, A Philosophical Examination* (pp. 125-137). Dordrecht: Kluwer Academic Publishers.

Matthews M. (1998). Introductory Comments on Philosophy and Constructivism in Science Education. In M.R. Matthews (Ed). *Constructivism in Science Education – a Philosophical Examination.* (pp. 1-10). Dordrecht: Kluwer Academic Publishers.

Matthews M. (1992). History, Philosophy and Science Teaching: The Present Rapprochement. *Science & Education, 1 (1)*, 11-47.

Mintzes, J. ; Wandersee, J. (2000). Reforma e Inovação no Ensino da Ciência: uma visão construtivista. In J. Mintzes, J. Wandersee & J. Novak (Eds.) *Ensinando Ciência para a compreensão – uma visão construtivista* (pp. 44-67). Lisboa: Plátano Edições Técnicas.

Niaz, M. *et al.* (2003). Constructivism: Defense or a Continual Critical Appraisal – A response to Gil-Pérez et al. *Science & Education*, *12,8*,787-797.

Nola, R. (1998). Constructivism in Science and in Science Education; A Philosophical Critique. In Michael Matthews (Ed.), *Constructivism in Science Education – A Philosophical Examination* (pp. 31-59). Dordrecht: Kluwer Academic Publishers.

Novak, J. (1990, July) Human Construtivism: A Unification of Psychological and Epistemological Phenomena in Meaning Making. In *Fourth North American Conference on Personal Construct Psychology*, San Antonio, Texas.

Novak, J. (1993). Human Constructivism: a unification of psychological and epistemological phenomena in meaning making. *International Journal of Personal Construct Psychology, 6,* 167-193.

Novak, J. (1997). *Teoría y práctica de la educación* (8ª reimp.). Madrid: Alianza Universidad.

Novak, J. (2000). A demanda de um sonho: a educação pode ser melhorada. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.) *Ensinando ciência para a compreensão – uma visão construtivista* (pp. 22-43). Lisboa: Plátano Edições Técnicas.

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

Novak, J.; Gowin D. (1999). *Aprender a Aprender*, 2ª ed. Lisboa: Plátano Edições Técnicas.

Sebela, M. (2003) *Using teacher action research to promote constructivist classroom learning environments in Mathematics in South Africa*. Thesis presented for the Degree of Doctor of Mathematics Education of Curtin University of Technology.

Soares, M.; Valadares, J.; Malheiro, M. (2006). Ambientes construtivistas de aprendizagem e aprendizagem significativa da ciência. Actas do *V Encuentro Internacional sobre Aprendizage Significativo*, Universidad Autónoma de Madrid:, Centro Superior de Estudios Universarios, La Salle.

Staver, J. (1998). Constructivism: Sound Theory for Explicating the Practice of Science and Science Teaching. *Journal of Research in Science Teaching*, 35, 5, 501-520.

Taylor, P., ; Fraser, B. (1991). Developing of an instrument for assessing constructivist learning environments. Paper presented at the *Annual Meeting of the American Educational Research Association*, New Orleans, LA.

Taylor, P., Fraser, B. ; White, L. (1994). The revised cles: A questionnaire for educators interested in the constructivist reform of school science and mathematics. Paper presented at the *Annual Meeting of the American Educational Research Association*, Atlanta, GA.

Trowbridge, J. & Wandersee, J. (2000). Organizadores gráficos guiados pela teoria. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.) *Ensinando ciência para a compreensão – uma visão construtivista* (pp. 100-129). Lisboa: Plátano Edições Técnicas.

Von Glasersfeld, E. (1996). *Construtivismo radical: uma forma de conhecer e aprender*. Lisboa: Instituto Piaget.

Valadares, J. (2001, Maio). 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.

Valadares, J. (2007). Constructivist and Investigative Learning Environments in Distance . Proceedings of the *EADTU 20th Anniversary Conference*: "*International courses and services online*", Lisbon.