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THE USE OF MIND MAPS AND CONCEPT MAPS IN QUANTUM MECHANICS AT HIGH SCHOOL LEVEL

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Abstract: In this paper, we discuss some preliminary findings based on the implementation of a Potentially Meaningful Teaching Unit (PMTU) in four different classrooms of the third year high school, in a public school in a hinterland town of Rio Grande do Sul, the southernmost state of Brazil. The proposed content for this implementation deals with concepts linked to quantum physics (quantization, uncertainty, state, and superposition of states), which we have organized according to the principles of the Meaningful Learning Theory (MLT), such as progressive differentiation and integrative reconciliation. It analyzes mind maps and concept mapping, with a focus on their structure and on the changes that have occurred in the process of comparing these maps. It also includes students' comments on the development of their own understanding of the concepts this research proposal has approached. Notwithstanding the incompletion of its results, this study can provide some evidence of the occurrence of meaningful learning, which constitutes the main objective of the implementation of a PMTU.

1 Introduction

The teaching of physics in high school has not managed to go along with the scientific and technological advances of these last decades. The curriculum is not up to date and contextualized. It is in this direction that we look for finding a way of bringing together classroom contents to the reality of our context today. Thus, we aim at promoting more meaningful teaching and learning.

When the contents of physics are presented in the traditional mode, they can cause in the students the lack of motivation and interest, mostly if they are approached expositively and monologically, without the use of resources and instruments that might call the students' attention and arouse the interest of this generation heavily linked to technology. At this point we get to the contents of physics taught in the classroom, in which in spite of the various initiatives of including Modern and Contemporary Physics to the high school curriculum (Silva & Almeida, 2011; Carvalho Neto et all, 2009; Ostermann & Moreira, 2000), its teaching still meets many drawbacks and it does not even happen. Consequently, many topics that are relevant for the understanding and observation of the way of life of this new generation are not taken into consideration.

In order to, at least partially, attend to this state of affairs, we believe that the insertion of contents of quantum physics in the high school curriculum is really necessary so as to face technological advances and the dissemination of feasible alternative representations, which might lead to hindrances in understanding them. However, the approach to quantum physics cannot be made in the conventional way it is usually done; instead, it needs to be addressed in such an engaging manner that students can get motivated to its lessons. This proposal has been developed according to the steps of the Potentially Meaningful Teaching Units, or PMTUs (Moreira, 2011), according to which, initially, a survey of the students' prior knowledge is made and, then, content is presented in a more general form. Next, each topic of the content receives a more specific treatment aiming at its progressive differentiation and integrative reconciliation.

2 Theoretical Framework

This proposal agrees with the perspective of the Meaningful Learning Theory, MLT (Ausubel, 1968; Ausubel, 2000), and it is based on the protocols of the Potentially Meaningful Teaching Units, PMTU (Moreira, 2011).

The PMTUs comprise stages that, in the sequence in which they are proposed, attempt at promoting meaningful learning. They consist of eight steps, or stages, that serve as a guide for the development of the PMTUs (Moreira, 2011) and it is up to the teacher to look for the best way of following these steps and to adapt them to his/her school reality. Therefore, the content has been carefully selected and organized so as to make the quantum physics instructional materials potentially meaningful, that is, they should present logical meaning (such as structure, organization, examples, adequate language) and, furthermore, they should be related to the needs of the third year of high school. The basic concepts to be developed here should be quantization, uncertainty, state, and superposition of states.

According to Ausubel (1968; 2000) the isolated variable that has the greatest influence on the learning of new contents is prior knowledge, or subsumer, to which new knowledge will be anchored. A subsumer can incorporate representations, schemes, models, personal constructs, alternative conceptions, invariant operators, which means that it includes cognition processes that already exist in the learner's cognitive structure and that are available to be related to the content he/she is to learn.

Therefore, we verified the students' prior knowledge by using mind maps (Buzan & Buzan, 1994; Ontoria, De Luque & Gómez, 2004) and by asking them about their ideas about quantum physics, which they answered orally in the classroom as a whole. Mind maps display totally free associations and present key-ideas that are interrelated and ramified so as to form a structured network, with nodes and connections, which are especially adequate when one wants to identify subsumers.

As an immediate follow-up, we developed the PMTU proposal that considered the principles of progressive differentiation and integrative reconciliation, which deal closely with the programmatic approach of the content. Progressive differentiation estimates the most general and inclusive concepts or ideas of the content that should be introduced right at the beginning and be progressively differentiated along the teaching process, in terms of details and specificities, whereas integrative reconciliation anticipates that teaching should explore linkages between or among ideas and concepts, pointing out relevant similarities and differences while reorganizing knowledge and clarifying ideas.

Thus, concepts were simultaneously approached, initially at a maximum level of inclusiveness and, little by little, they were presented again at increasingly higher levels of specificity, but always linked to what had been already studied. We promoted progressive differentiation by starting at the most general and inclusive and moving on to the most specific level, while integrative reconciliation occurred when we re-approached general level ideas and concepts based on specific ideas and concepts.

New knowledge, which was generated by the interaction between subsumers and information presented, seems to be naturally different from the latter, and it was shown by the students in the construction of their concept maps (Novak, 1997; Novak, 1980) as well as in a set of activities prescribed in the PMTUs. A concept map is a hierarchical diagram of concepts and linkages between, or among, concepts through which we can perceive that some of them are more relevant, more inclusive, more structuring than others. Associations are directly related to the context of the subject matter, whereas mind maps deal with associations that are always free. In a concept map, relations between/among concepts are evidenced through lines that link them together. It is on these lines that propositions are placed, and they help to make explicit the kind of relation there is between/among the linked concepts and they attempt to reveal the conceptual structure of the content that is being diagrammed.

This proposal follows the principles we have so far described. Hence, at first we surveyed the students' prior knowledge, then, we introduced the content in a general manner. Afterwards, each key-concept was dealt with in a very specific and detailed mode. The basic concepts developed in this PMTU were quantization, uncertainty, state, and superposition of states, which are rated as crucial for the understanding of quantum physics.

3 Methodology

Implementation of classroom activities occurred with four different third year high school classes in the E. E. E. M.[1] Carlos Antonio Kluwe, Bagé, RS, Brazil. The four classes were divided into two groups of two classes each, with the goal of better evaluate the efficacy of this proposal and to allow for modifications in the original proposal whenever needed. The first group started its activities on the 10th of October 2011, and it had 18 meetings, while the second group started on the 31st of October, 2011, with 15 meetings.

The concepts–quantization, uncertainty, state, and superposition of states—were approached conceptually and according to Copenhagen interpretation. The purpose, here, was to value phenomena interpretation and the simplest equations without entering more advanced mathematical complexities, having in mind that this implementation occurred in high school.

Since meaningful learning and the mastery of a field of knowledge are progressive, the focus of this paper in on the students' progress along the process and not on their final outcomes. For this reason, questions and situations that aimed at verifying the students' comprehension and assimilation of meanings throughout the course of the PMTU implementation were proposed.

[1] Public (State) High School Carlos Antonio Kluwe in Bagé, a town in Rio Grande do Sul (the Southernmost state of Brazil).

For a better knowledge organization, the students were asked to produce some kind of material (task) at each step of the PMTU as a learning outcome. Altogether there were six tasks developed by the students: mind map, initial questionings, free choice task developed after the first text, concept map, individual evaluation/self evaluation, and class newspaper/paper. Students' tasks are clarified in Table 01 and they are related to the steps of the PMTU steps.

Table 01: Tasks performed by the students at each step of the PMTU.

Step	Step objective	Student's task
1	Theme definition.	-
2	To externalize subsumers.	Development of mind maps in pairs. Discussion about some of the guidelines proposed by the teacher, by the large group (the whole class).
3	To sharpen students' curiosity and to relate knowledge using introductory level advance organizers.	Reading of the article *Física Quântica para Todos* (partially adapted from Nunes, 2007). Text discussion in small groups. Production of a free-choice material, in groups.
4	Presentation of concepts relating them to previous examples and discussions.	Watching the documentary film *Tudo sobre Incerteza – Mecânica Quântica* (Discovery, 2007). Construction of concept maps by the same pairs as in step 2.
5	To approach the same content again, using the comparison of the maps in step 2 with the ones obtained in step 4, so as to address ideas that have been disclaimed and to observe what has been added.	Qualitative comparison between mind maps and concept maps, in pairs, according to participation in the previous steps. Oral and written report of this moment.
6	Closing of the content with concept presentation at the maximum level of complexity, but in agreement with the level of schooling.	Large group discussion about the approach used in drawings (illustrations) and charges about quantum physics concepts. Production of a small class newspaper in the large group, with various resources, such as small articles, charges, comic strips, and/or illustrations/drawings about the studied topics. Resources are those selected by the group.
7	Summative evaluation. Formative evaluation. The teacher evaluates students' performance and it is based on the two evaluations in an egalitarian manner.	Individual summative evaluation happens in the classroom with open questions involving the unit key-concepts. Individual formative evaluation according to the activities developed by the students and to the teacher' s notes along the PMTU.
8	Evaluation of the PMTU itself. Final integrative comments about the studied contents.	Oral analysis of the proposal as a whole, including students' performance in the evaluations and tasks, and the teaching strategies as well as the students' own learning.

For this proposal, activities described in steps 2 and 4 were selected together with their modifications along the process presented here were discussed, as well as the evolution in the comprehension of concepts and in the established linkages between/among them, which had been displayed in the students' mind maps and concept maps. These features can be viewed as an indication of the occurrence of meaningful learning.

The use of mind maps allows the students to express themselves freely and, therefore, this tool permits us to look for external influences in the process of subsumer development, such as, for instance, issues that are treated by the media, contributions that come from previous years of schooling, or from school contents students have already studied. On the other hand, concept maps, because of their own structure, do not enable students to have the same freedom they have with mind maps and, thus, it might be more difficult for the researcher/teacher to verify the external influences in the development of subsumers and in the grasping of meanings derived from the subject matter studied. In this study, we expected the external influences upon quantum physics to become spontaneously extinct. However, the students did not receive any guidance towards the choice of concepts they should use, though they were instructed to follow the rules for concept mapping and to relate to the concept maps their knowledge of quantum physics.

4 Findings

We present here some signs, or indicators, of meaningful learning shown by the students in their maps: the presence/absence/modification of ideas when comparing the mind maps, in the early stages of this intervention, with the concept maps that were developed after the presentation of the quantum physics contents. The relations observed in those maps were qualitatively analyzed, and some of the students' comments on the evolution of these linkages when they compared the two activities (mind maps and concept maps) are also presented.

Maps of three pairs of students are discussed: the first two figures correspond to pair A, pair B drew figures 03 and 04, and pair C constructed the last two maps.

Figure 01 shows a mind map by pair A, and it presents a radial format around the central concept. We can also notice the presence of terms linked to the pair' s prior knowledge (Planck, uncertainty, photon, black body, etc.), though they are directly connected to quantum physics, they do not have a hierarchical organization and linkages that might indicate the kind of relation the students have established. Whereas, the concept map of this same pair, figure 02, displays how concepts are hierarchically in the pair's cognitive structure. At the very top of the map, it shows atomic particles related to classical physics, but without any connecting element. From classical physics it branches out in three: Newton and gravitational theory; superconductiveness and electronic devices; and quantum physics, in which the connective used indicates that classical physics has opened the way to quantum physics. It might be stated that this map shows this sequence as a result from the way this content have been treated in the classroom. We can also notice that some concepts that appear in the mind map have been reorganized: from quantum physics on they follow new linkages, such as uncertainty, duality, superposition of states that lead to the present atomic model. All these concepts are related to modern physics, and from it they branch out into ramifications of examples of quantum physics applications in the macroscopic world.

This map, as all the others, was drawn in the classroom. Notwithstanding that some of its concepts do not present any connectives and that some of the ideas appear without a hierarchical definition—they do not appear as concepts or as connector, or linkages—we can notice that there is clearness in the relations established, which agree with quantum physics, Thus, we might say that these characteristics point out that this particular pair has meaningfully learned the given contents, as they have organized their prior knowledge adequately.

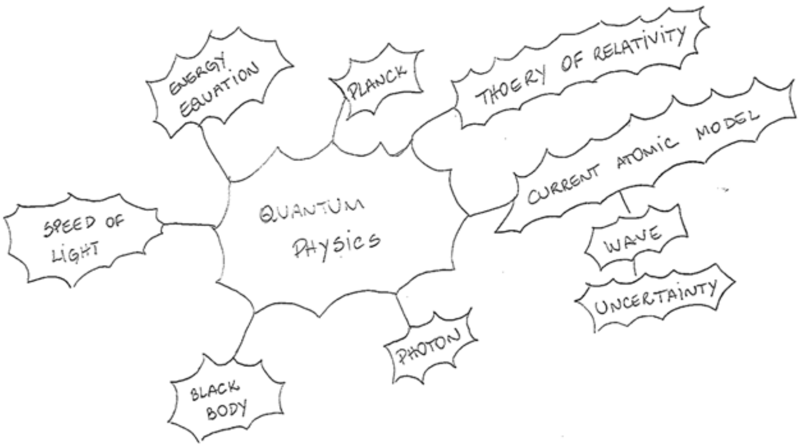

Figure 01: mind map of pair A

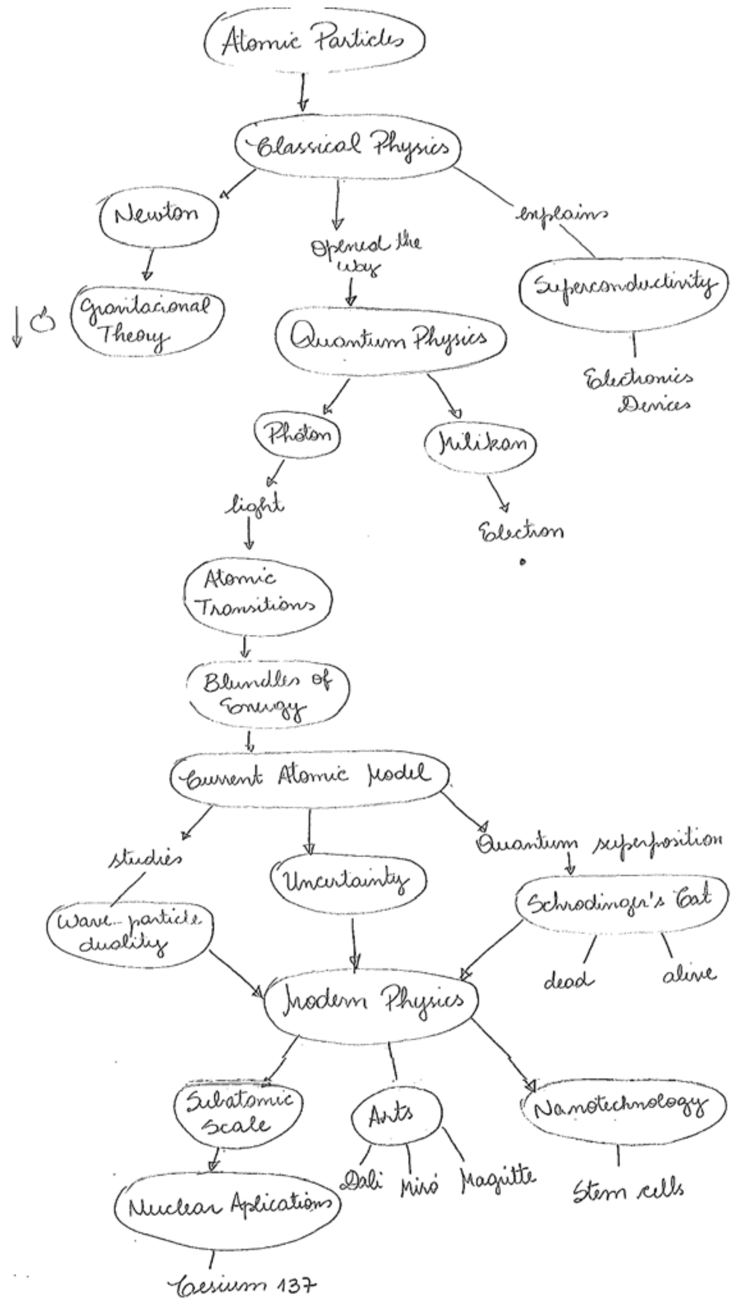

Figure 02: a concept map of pair A

Figure 03 displays a mind map developed by pair B, and its associations have to do essentially with atomic particles (protons, electrons, etc.) and with concepts they have already studied in previous situations in the disciplines of physics and chemistry (electromagnetic waves, quantum numbers). We cannot perceive in it linkages between/among the concepts, but only first-degree linkages with quantum physics, without any connectives. This pair has used a cloud formal to indicate concepts, which can be linked to thoughts since this is a free creation.

The concept map this pair has constructed, figure 04, comprises most of the concepts approached in the PMTU. Knowledge seems to be more organized, which can be observed in the linkages between/among concepts and in the connecting words they have used here. We can also notice the formation of small tree-like forms with the concepts directly organized among themselves. Although it does not shows all the connecting words (connectives), linkages agree with quantum physics. This pair demonstrates a fairly good understanding of content, which serves as a sign to the occurrence of meaningful learning of the externalized concepts.

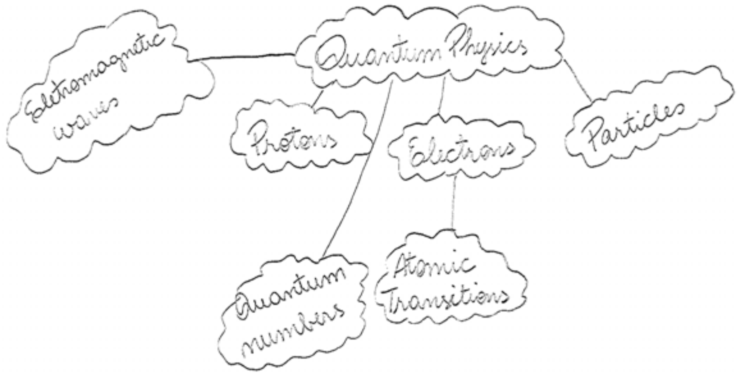

Figure 03: mind map of pair B.

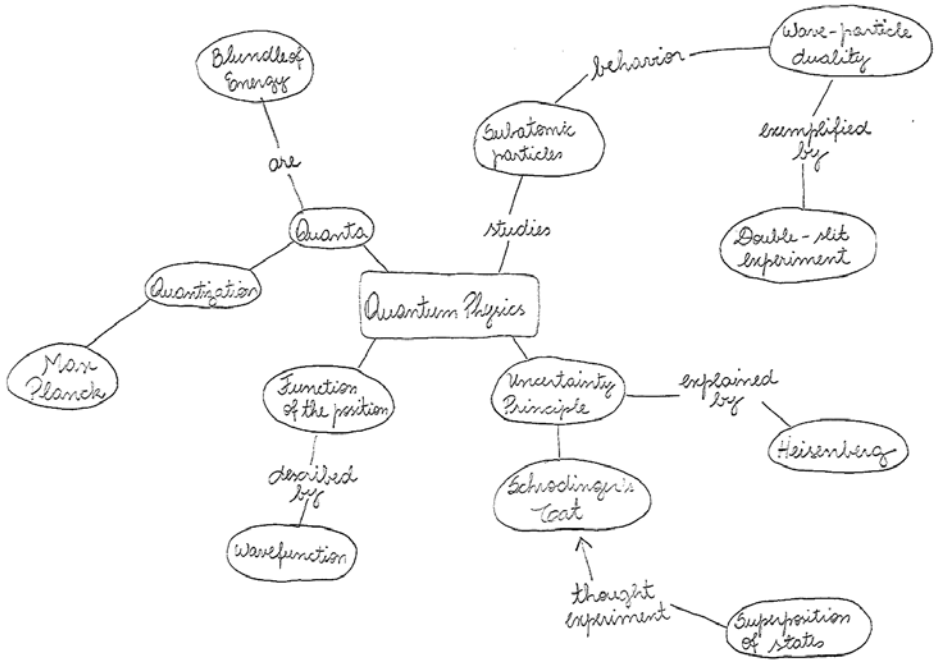

Figure 04: a concept map of pair B.

According to figure 05, which presents the mind map of pair C, students have performed free associations, without connecting elements and, possibly, without knowing how each term relates to quantum physics. This might be noticed in some unbound terms, such as “variety” and “universe”. There is a hierarchy for magnetism and magnet, as well as between numbers and formulae, but these concepts and others presented through the map are not related directly with quantum physics, but to electromagnetism (electricity, polarity) and to the traditional approach to contents of physics (quantity, theories).

The concept map in figure 06 displays some of the concepts more than once (electron, proton, atom), while the concept ‘quantum’ that is highly considered in quantum physics appears there just as a connecting word. The sentence “quantization is a mathematical procedure for the construction of a quantum model for a physical system”, as well as application examples such as “development of faster computers” and complements to theory like “modernness” and its ramifications. Furthermore, these students do not seem to have a clear view of the concepts since, basically, the contents presented in the classroom is shown as linked to the central concept by means of the connecting word “subdivisions”, which does not correspond to the scientifically accepted relation between these concepts. Linkages that are seen as external to the quantum theory, which in this concept map are represented as related to spirituality and consciousness, might be there as outcomes from verbal interactions in the classroom and we expected, at the end of the activities involved in the development of the chosen content, these issues not to be related to quantum physics anymore. Although some of the relations between/among concepts already appear in quite a clear way, this pair needs to clarify others. We can proceed to say that learning is evolving, though it has not become effective yet.

Figure 05: mind map of pair C.

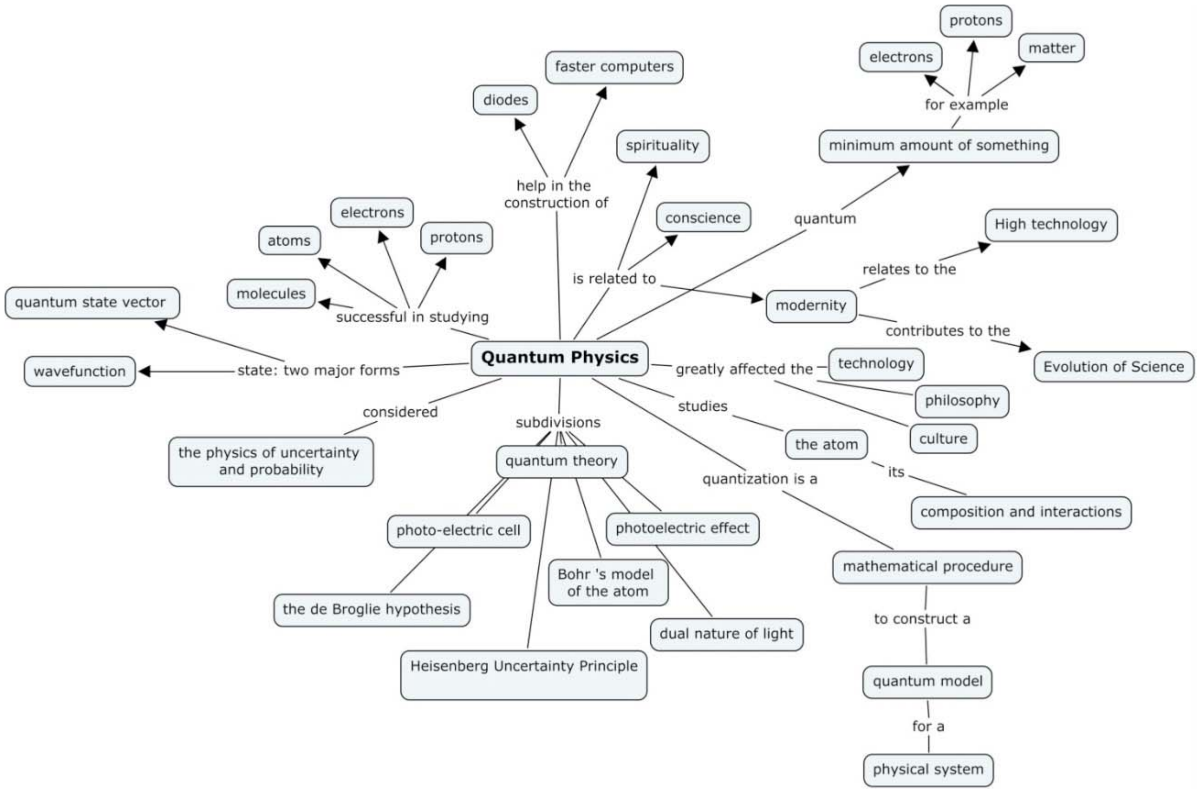

Figure 06: concept map of pair C.

Considering the statements already made, some signs of meaningful learning were found here because the students expressed concepts and relations as they are scientifically accepted in the quantum physics area, in agreement with the level of understanding expected at high school. Besides, each pair of students thought about the evolution of their maps, as it is presented in table 02, which corroborates these observations.

More evidences of meaningful learning might be found in the other performed tasks developed by the students since this research is still in the data collecting stage.

Pair A	"The second map was a lot different from the first one because our idea about each presented concept had changed, and this helped us improve our understanding of each part of the content. And the connecting words between/among the concepts helped us to better retrieve the subject matter".
Pair B	"In the first map, we did not have a hint on what we were writing, and we just placed irrelevant terms there. In the second one, we knew the concepts and linkages we wanted to place there, since our knowledge had increased a lot."
Pair C	"Comparing the maps, we can perceive a relevant evolution from the first map to the second one. Besides the indicated program for developing our work, the examples of maps were of great importance. Classes in the multimedia classroom were another important constant. However, there is a lot to improve notwithstanding our evolution from the first to the second map. We did not have a concrete opinion about the topic, which was unknown to us, so that we wrote words that could have any linkages and, furthermore, we did not have enough knowledge to construct a concept map."

Table 02: students' thoughts about the comparison of their mind and concept maps.

5 Final Remarks

Although data analysis has not be concluded yet, it seems possible to anticipate some evidences of meaningful learning when we compare mind maps—drawn at the beginning of this intervention as a means to detect subsumers—with concept maps—indicators for the evolution of the students' knowledge of quantum physics—exploring the relations between/among concepts scientifically accepted. The use of maps has been a good resource to observe knowledge evolution, and it has helped the teacher/researcher and the students to identify linkages that have been assimilated, as well as comprehension gaps, facilitating the review of concepts that have not yet been totally elucidated in the next steps of the PMTU proposal.

We still need to examine the data related to all the other activities performed by the students, in which we expect to obtain more consistent indicators of meaningful learning. The approach to quantum physics in high school has shown itself feasible and it has brought promising outcomes. The use of PMTU as a methodological proposal is innovative for it comprises quite an up-to-date approach.

The use of PMTU, with resources such as mind maps and concept maps, can be much more than a tool to promote meaningful learning: it can become a motivating option for curriculum improvement and for the insertion of quantum physics topics of modern and contemporary physics in high school

6 References

Ausubel, D. P. (1968). Educational psychology – a cognitive view. New York: Holt, Rinehart & Winston. 685p.

Ausubel, D. P. (2000). The acquisition and retention of knowledge: a cognitive view. Dordrecht: Kluwer Academic Publishers. 212p.

Buzan, T. & Buzan, B. (1994). The mind map book. New York, NY: Dutton Books. 320p.

Carvalho Neto, R. A.; Freire Júnior, O.; Silva, J. L. P. B. (2009). Improving students' meaningful learning on the predictive nature of quantum mechanics. *Investigações em Ensino de Ciências*, 14(1), 65-81.

Discovery. (2007). Documentário Tudo sobre Incerteza – Mecânica Quântica – Partes 1 a 6. Parte 1 disponível em: <http://www.youtube.com/ watch?v=O1dHym14W5Q&NR=1>. Acesso em: 08 mar. 2012.

Moreira, M. A. (2011). Unidades de Enseñanza Potencialmente Significativas – UEPS. Aprendizagem Significativa em Revista / Meaningful Learning Review, 1(2), 43-63.

Novak, J. D. (1977). A theory of education. Ithaca, N.Y.: Cornell University Press. 295p.

Novak, J. D. (1980). Uma teoria de educação. São Paulo: Pioneira. Tradução de M. A. Moreira do original A theory of education.

Nunes, A. L. (2007). Física Quântica para Todos. In: Simpósio Nacional de Ensino de Física, XVII, 2007, São Luis. Anais eletrônicos. São Paulo: SBF, 2007.

Ontoria, A., De Luque, A. & Gómez, J.P.R. (2004). Aprender com mapas mentais. São Paulo: Madras. 168p.

Ostermann, F. E.; Moreira, M. A. (2000). Uma revisão bibliográfica sobre a área de pesquisa Física Moderna e Contemporânea no Ensino Médio. *Investigações em Ensino de Ciências*, 5(1), 23-48.

Silva, A. C.; Almeida, M. J. P. M. (2011) Física Quântica no Ensino Médio: o que dizem as pesquisas. Caderno Brasileiro de Ensino de Física, 28(3), 624-652.