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A COMPARATIVE ANALYSIS ON THE USE OF CONCEPT MAPS AS AN INSTRUCTIONAL RESOURCE FOR THE GRASPING OF MEANINGS OF KEY CONCEPTS OF QUANTUM MECHANICS BASED ON THE DOUBLE SLIT EXPERIMENT

Iramaia Cabral de Paulo, Universidad Federal de Mato Grosso, Brasil
Marco Antonio Moreira, Universidade Federal do Rio Grande do Sul, Brasil
Concesa Caballero, Universidad de Burgos, Spain

1 Introduction

Concept maps, on a simplified way, can be considered as diagrams that show the possible linkages among given concepts related to a field of knowledge, or to a specific part of it, expliciting feasible conceptual relations and hierarchies. They were conceived by Joseph Novak and his graduate students at Cornell University, USA, in the 70s, and their use today becomes increasingly important as a strategy to facilitate meaningful learning, which was initially proposed by Ausubel and has been continuously developed by Novak and Gowin, and more recently by Moreira.

The aim of this paper is to present a comparative study of the use of concept maps as a teaching and/or learning resource or strategy. It integrates a more comprehensive research project developed by the authors on the learning of the basic concepts of Quantum Mechanics in secondary schools and in college courses that aim at the preparation of physics teachers.

Concept maps were used to show the hierarchical relations among concepts presented to students. These concepts derived from a textbook that describes the double-slit experiment with neutrons. Students were expected to unveil the hierarchical relations of subordination and superordenation that could indicate the grasping of meanings of the most inclusive concepts of the teaching content.

2 Experimental procedure - A sample

A pedagogical text was developed to describe the double-slit experiment with neutrons, which has been considered by Niels Bohr the most important experiment of quantum mechanics because it deals with its fundamental principles: complementarity, non-determinism, and wave – particle duality (Paulo, 2006).

This research was developed in three stages, in the city of Cuiabá, Mid-Western Region, Brazil. The first one started in 2001 with students of a private secondary school in three classrooms of the first year of high school and it involved 80 students. They had three weekly meetings of 50 minutes each during the first bimester of that school year, which is about 8 weeks. The average age of the students was 15, with a low level of variability, which is in agreement with the expected age average for this year of high school in Brazil. At the time, the first author was the physics teacher of that school so that she could develop her research project with a long term interaction between herself and the students—according to Novak and Gowin (1984), and Moreira and Masini (1982) this is a relevant prerequisite for offering favorable conditions for meaningful learning to occur. The use of Concept Maps as an instructional resource became an everyday practice in the classes. Step by step the students, under the guidance of the teacher got familiarized with the drawing technique and with the presentation of the maps to their peers, and this offered them relevant moments for the negotiating of meanings.

The second stage was developed in July 2006, with public school teachers taking a continuing education course with around 50 participants, average age between 30 and 50, at the Federal University of Mato Grosso (UFMT), Brazil. The introductory contents of Quantum Mechanics (QM) were developed during four weeks, morning period with a four hour period per day, in which the same text used with a previous sample was used as an introductory resource. On the other hand, during the afternoon period, the Meaningful Learning Theory, together with the construction of concept maps and V diagrams - as facilitating instruments for meaningful learning - constituted the central themes of these four weeks. The learners had, then, the opportunity of constructing concept maps on different topics of physics, so that in the QM classes the teacher could ask the students to collectively construct and analyze their concept maps.

In August 2007, the text "The Double-Slit Experiment" was once more used as a pedagogical resource in classes of the subject Structure of the Matter 1, of the course of Licenciature in Physics at the Federal University of Mato Grosso, Brazil, with a class of 18 students, whose average age was 20 with a very low degree of variability. These undergraduate students were being prepared to become high school physics teachers. After reading and discussing the text, they were asked to draw concept maps to be presented to their peers, who offered their reviews and suggestions on the maps. It seems important to emphasize that these students had not received any specific lessons on how to construct their concept maps, they just were shown some examples of maps on a diversity of topics together with brief explanations about how maps should be structured, and the learning possibilities they offered.

3 The Concept Maps

Concept Maps (CM) are instruments that agree with the Ausubelian idea that the people's mind comprises a hierarchical organization of ideas and concepts. If the maps are organized in such a way that allows for the more inclusive concepts to be at the very top of the hierarchy and the less inclusive below them, it is feasible to visualize, according to Ausubel (Moreira and Masini, 1982), movements of *progressive differentiation* (going downwards on the map) and of *integrative reconciliation* (going upwards on the map), of course this view we are using is metaphorical.

Concept maps offer evidences although frail for the comprehension of the linkages between or among the concepts involved and, possibly, of their epistemological foundations, that is, of how learners organize the various concepts they have in their minds. This feature is especially relevant here since the analysis of how quantum concepts are structured in the minds of high school students, teachers in continuing education, and undergraduate students, who are actually teachers in the initial stages of their teacher formation process, integrates the set of objectives of this study. CM might be used as tools for planning, for diagnosing conceptions held by students and teachers, and as instructional resources as well. Novak and Gowin (1984), in *Learning how to learn*, which is aimed at the classroom environment, describe how concept maps can help teaching the contents of the most diverse areas of knowledge. According to these authors, CM can be applied both to the teaching of subject matter and as an instrument for learners' evaluation. Novak's whole work attempts at convincing that concept maps, together with Ausubel's theory of meaningful learning, which underlies them, can be used in teaching practices, as a teaching-learning methodology, as well as an evaluation instrument. As it has been mentioned earlier, our emphasis here is on concept mapping as an instructional resource, and its use as instruments for evaluation ends up as a component of the teaching and learning processes of the educative event.

The teachers have to establish their own set of criteria to validate concept maps both qualitatively and quantitatively. However, it seems to us that their perception of the construction processes and the relevancy of the final product according to the proposed objectives should allow for a more adequate quantitative analysis of the concept maps. An educative event has its own particularities/features and the teacher might be the only one who knows about the development of the educational process, what the final product actually is, and whether or not the proposed objectives have been achieved. When concept maps are to be used, the set of criteria for the educative event can and should vary according to its pre-established priorities.

Drawing concept maps is a challenging educational activity for students because it requires creativity and critical thinking as far as it asks them to externalize concepts and their linkages in propositions that constitute the structure of the map itself. New linkages and meanings are constantly constructed, developed and improved. Thus, this kind of activity does not involve only those prior concepts already there in the learners' cognitive structure but it also involves the learners' skills to create and recreate new linkages, as well as new perceptions of conceptual relation.

Concept mapping as evaluation instrument, as we have already presented, requires a critical stand on the potential of CMs and a belief about the value of this activity for the construction of knowledge about a given field, in a way that might make concept maps activities differ from the usual trends in teaching and learning.

The main idea is to evaluate what the learner already knows in terms of concepts, and on how he/she structures them, organizes them hierarchically, differentiates, relates, discriminates and integrates them (Moreira, 2000). When we consider evaluation as a process, we can detect, during the drawing of the maps, aspects such as interaction with instructional material and with the work group (students and teacher), self reflectional process, which constitute steps necessary for the sharing of meanings and meaningful learning. These elements have a qualitative relevance that requires teacher's skills and common sense if we aim at a criterion-based analysis of the concept maps.

Novak and Gowin (1984) suggest a set of basic criteria for marking and assigning grades to the CMs as an attempt to a quantitative evaluation of cognitive performance concerning what should be the cognitive organization that is an outcome of meaningful learning, which involves hierarchical organization, progressive differentiation, and integrative reconciliation.

Three concept maps developed during teaching situations previously described are presented and briefly commented here, due to space limitations. They are samples drawn in class by three groups of students in the three distinct stages of schooling.

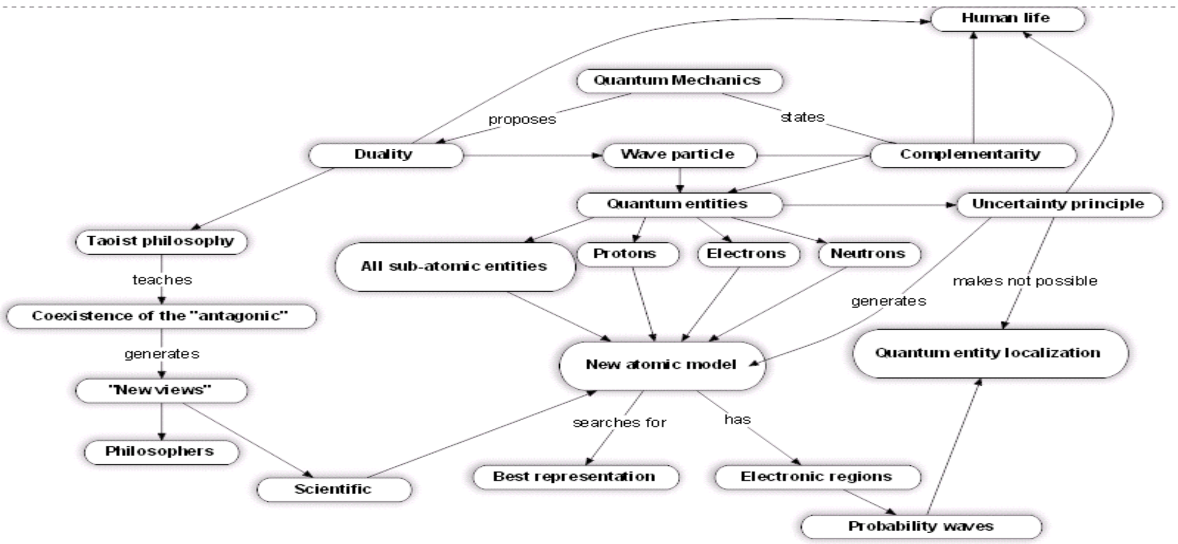

Figure 1. An example of concept map developed by a group of three students of the first year of high school.

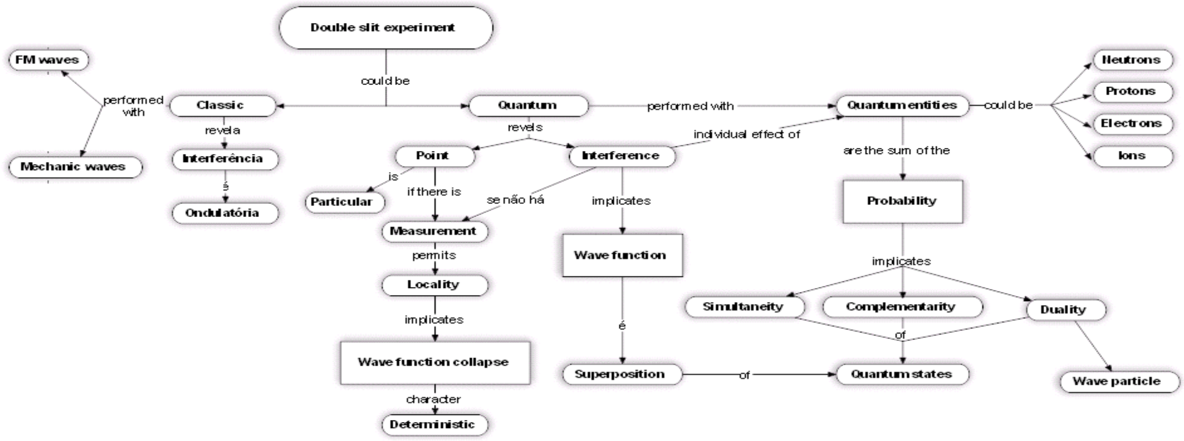

Figure 2. An example of a concept map drawn by a group of three high school physics teachers.

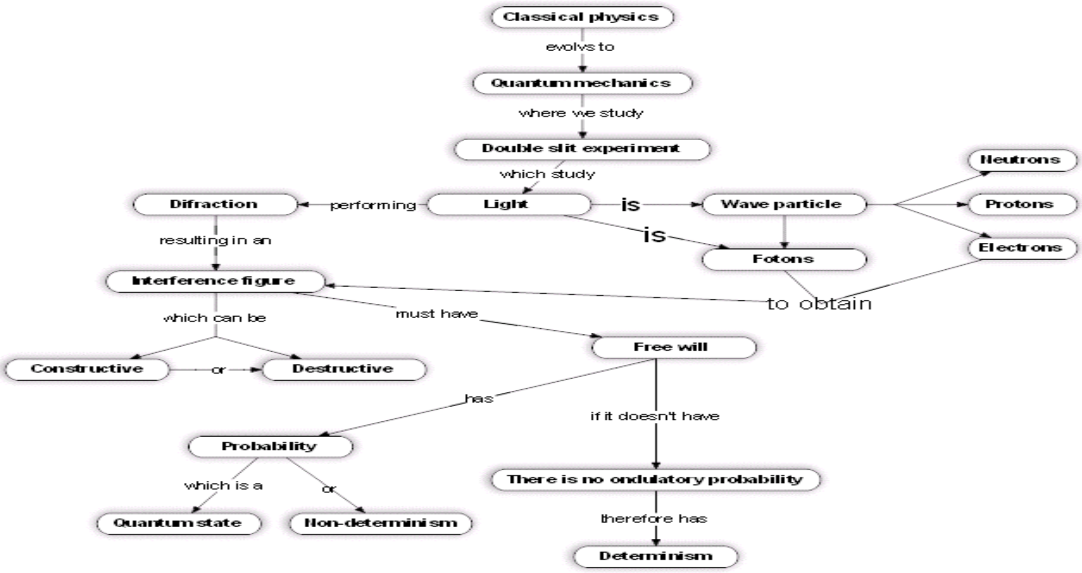

Figure 3. An example of a concept map drawn by a group of three students who are physics majors.

A pertinent fact that might be identified in these maps is that, without exception, the learners involved in this study have shown a rather sophisticated and similar conceptual organization that included the basic principles of Copenhagen Interpretation presented and discussed in the pedagogical text. Concerning morphology, we noticed that a vertical arrangement of the boxes does not necessarily mean a hierarchical organization. This can be perceived, for example, in the sequence of concets at the top of figure 1; to the left of figure 1, when Taoist philosophy is dealt with; in figure 3, it can be noticed in the concept of *classical physics*. This sort of arrangement might mean that it is a flow diagram, which constitutes another way of representing concepts, but it is not a concept map.

In all examples we can observe that students tend to hierarchically arrange concepts without organizing them vertically as a rule. Nevertheless, the hierarchical organization of concepts is a basic feature of concept mapping according to which horizontal levels of this hierarchy can present relevant relations of subordination and differentiation. As an example, in Figure 1, the concepts *light* and *wave-particle* show a subordinate relation from the perspective of science through the use of the linking verb, and it is possible to notice that this subordinate relation is valid. On the other hand, according to what might be observed in Figures 1 and 2, in the concepts wave-particles and quantum entities, respectively, we can verify that the vertical cell arrangement does not imply a hierarchical organization since it can be seen as a flow diagram. Progressive differentiation is an evident feature of concept maps, which can be an indicator of meaningful learning, however, this cannot be verified in relation to integrative reconciliation (shown only in Figure 2), suggesting that skill seems to be an ability that demands more time and conceptual maturity from the learners.

4 Final remarks

As it has been already mentioned, the examples of the concept maps present a good correlation of concepts that come close to what is expected for an initial conceptual construction of quantum mechanics. Nevertheless, whatever kind of analysis, be it quantitative or qualitative as the one performed here, does not guarantee the analysis of the concept maps to be free of any bias, since some of the difficulties become more explicit as about that a concept map might have a kind of hybrid hierarchy presenting relevant and valid linkages of subordination and differentiation. This seems to be critical according to the Novak and Gowin's criteria that privileged a hierarchical organization of concepts. In the same concept map, in some parts of it, small flow charts might appear that do not invalidate the linkages that have been established by the students between or among the concepts. The opportunities for the development of the maps and the students' oral presentations to explain them might be the most important aspect of the use of concept mapping since these spaces of critical thinking grant learners and teachers priceless educative moments of negotiating and sharing meanings about their idiosyncrasies concerning the subject matter and/or the content that has been taught. This, in turn, involves respect to diversity of opinions, ideas, and different modes of comprehension and acquisition of meanings.

A concept map reliability and its range of validity in the construction of knowledge are aspects that deserve a special attention from the teacher, taking in consideration the set of criteria he/she has established beforehand, so as to insert them as an activity of the educative event, although they can be used as an instructional resource and/or an instrument for the evaluation of constructed knowledge. Criteria may vary according to the context in which concept maps are used, and these criteria might include the hierarchical organization of concepts, crossed linkages, the existence or not of key concepts, as well as other criteria set by the teacher. The opportunity students have of experiencing the drawing a concept map and of thinking about the conceptual linkages they can come up with, and of sharing meanings with their peers stands as one of the most relevant features involved in using concept maps in the classroom as instruments with a great potentiality in facilitating meaningful learning and in getting evidences of its occurrence.

We emphasize that a relevant difference between and among the maps we have analyzed concerning their conceptual a structural quality, which can be important when we consider that the students here have come from different levels of schooling. This might indicate that the instructional material used in this research and the concepts involved in the study of the different philosophical principles of the Copenhagen Interpretation can be accessed by people of diverse levels of age and schooling.

5 References

Ausubel, D. P. (1968). *The acquisition and retention of knowledge: A cognitive* view. Dordrecht: Kluver. Academic Publishers, 2000.

Moreira, M. A. & E. F. S.Masini (1982). *Aprendizagem Significativa, A Teoria de David Ausubel,* Editora Moraes, São Paulo.

Moreira, M. A. (200). *Aprendizagem Significativa Subversiva,* Atas do III Encontro Internacional sobre Aprendizagem Significativa, 11 a 15 de setembro de 2000, Peniche, Portugal.

Novak, J. D. & D. Gowin (1984). Learning How to Learn, Cambridge University Press, Cambridge.

Paulo, I. J. C. (2006). Critical Significative Learning of concepts Quantum Mechanics, according to the Copenhagen Interpretation, and the problem of the proposals diversity on teaching Modern and Contemporary Physics in the secondary level. 2006. 235p. Doctoral thesis – Science Faculty, University of Burgos, Burgos, Spain.