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CONCEPT MAPPING AS A STRATEGY TO EXPLORE TEACHERS' MENTAL REPRESENTATIONS ABOUT THE UNIVERSE

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Abstract. Concept maps are especially useful tools to identify knowledge available in the subjects' cognitive structure and also to present the ideas, concepts, and propositions necessary for the construction of new meanings related to a specific scientific field, such as cosmology. The theories of mental models by Johnson-Laird and of conceptual fields by Gérard Vergnaud have been used as a framework for the development of this study. It presents findings of a qualitative analysis of concept maps used as pedagogical strategy to inquire about the mental representations, and their possible evolution, held by a sample of teachers, who participated in the activities offered by the Barranquilla Planetarium, in Colombia, in relation to models of the universe.

1 Introduction

This paper is part of a research project that aims at exploring and interpreting, within the framework of cognitive psychology representational theories and cosmological models developed throughout history, the internal representations of science teachers based on their external representations of the universe and on the elements they use to explain them (Larios, 2007).

It was developed in two stages: the first was an exploratory one to characterize the science teachers' mental representations about the universe; the second stage was experimental in which a methodological strategy was applied based on the converging points of the theories of mental models (Johnson-Laird, 1983) and of conceptual fields (Vergnaud, 1990; Moreira, 2002) to depict the evolution of mental representations and the knowledge those teachers had about scientifically accepted cosmological theories and models.

The underlying assumption that to promote meaningful learning one must master the scientific content to be taught (Moreira, 2006) guided the design and application of a methodology, during the experimental stage, that would help getting to know the degree of understanding about the universe and the conceptual mastery of the underlying theories, laws, and principles linked to the cosmological models of a sample of five teachers of social and natural sciences.

Among the instruments used in the research, concept maps have shown to have great potential in allowing for an approximation to the representations of the teachers as well as their possible evolution through conceptual enrichment favored in the pedagogical intervention (with the teachers involved in this study, in the planned activities for the sessions of the Planetarium, in Barranquilla). Research findings reported here correspond to the qualitative interpretative analysis of the concept maps produced by the teachers during the experimental stage of the research, and they might point out to the evolution of the initial models about the universe towards to other ones with a closer agreement to accepted scientific models.

2 Theoretical framework

Some elements of the theories of mental models by Johnson-Laird and of conceptual fields by Gérard Vergnaud are emphasized here as relevant to the aims of this paper. Coincidences or points of convergence, between the two theories are also pointed out since they were important to the planning of the methodological approach for the sessions with the teachers in the Planetarium, as well as in the interpretative analysis of the representations about the models of the universe suggested in the concept maps.

2.1 Johnson-Laird's mental models

Johnson-Laird's (1983) theoretical approach assumes that human beings do not apprehend the world directly, but they do so through the representations of the world they construct in their minds. Johnson-Laird believes that "*to understand a physical system or a natural phenomenon one needs to have a mental model of this system that will allow him/her—the person who will build it—to explain it and to predict about it*" (1983, p.430).

According to this theory, mental models are considered as structural analogues of state of things in the world and are instruments of understanding and inference. They have an internal structure, that is, they are made of *elements* and *relations*, and they are constructed from some basic elements, which the author calls them *conceptual primitives*, that are innate and are organized within a given structure. They might be basically propositional or imagistic or they might contain both propositions and images. Johnson-Laird still conceives the existence of what he calls innate *procedural primitives*.

Mental models, according to the author, should not have any elements without function and meaning (1983, p. 419), which indicates that, when facing a situation, elements that have been chosen to interpret it together with the conceived, or perceived, relations among them establish an internal representation that serves as a substitute for this situation. When internally manipulating these substitutes, some properties of the system, as well as inexplicit relations among their components, can be recognized or directly inferred (Moreira, 2005). In this regard, we believe the theory of mental models can offer support to the investigation of the construction processes and conceptual development of individuals. Thus, when we get to know what elements are involved in a mental representation about a particular event (in this paper about mental models) and, furthermore, what relations are established among them, we might infer the individuals' stage of conceptual development.

2.2 Gérard Vergnaud's conceptual fields

Vergnaud's theory (1990; Moreira, 2002), similarly to Johnson-Laird's theory (1983), complies with the idea that knowledge is pragmatically organized so that it is crucial to pay attention to what a person does and to the way he/she organizes his/her behavior when facing concrete situations. According to this theoretical standpoint, an individual's cognitive structure is continuously modified through his/her own experiences, which in agreement with Ausubel (1976; 2002) emphasizes the role played by prior knowledge in the knowledge construction processes, thus, Vergnaud's theory pertains to the constructivist paradigm.

He believes that knowledge is organized in *conceptual fields* defining them as a formal and heterogeneous set of problems, situations, concepts, relationships, structures, contents, and operations interconnected and presumably interwoven during the acquisition process (op.cit). They are, then, units of study that are helpful to attribute meanings to acquisition problems and to observations related to conceptualization. Vergnaud (op.cit) maintains that conceptualization is the central nucleus of cognition, that is, knowledge is constructed around concepts so that it is strictly necessary to pay much attention to the conceptual aspects of the schemes and to the conceptual analysis of the problem situations for which learners develop their schemes, both in formal teaching and in everyday life. In agreement to Vergnaud's ideas (1998), we can say that: a) a concept does not form itself within just one kind of situation; b) it is not possible to analyze a given situation with the use of only one concept; c) the construction and appropriation of all the properties of a concept or of all the aspects involved in a situation are comprehensive and lengthy processes.

In this theory, the relevance of the subject's *action* is emphasized as a mediator of conceptual evolution. Therefore, it is fundamental to face students with a variety of diverse situations in different degrees of complexity and whose response calls for the availability of specific concepts, as in the case of this research those related to cosmological models. This underlying idea is the key factor for the methodology applied here since its main goal has been to attain an improvement in the teachers' mental representations in comparison to the ones presented during the exploratory stage. Concept maps are relevant tools to analyze the knowledge individuals have in their minds (Cañas, 2005; Novak, 1998), and for this reason they were used in the methodology of the activities developed in the Planetarium with the teachers involved in this research.

As a follow-up to what has been already set forth, some ideas that are shared by these two theories—mental models and conceptual fields— will be concisely presented.

2.3 Which elements are shared by the two theoretical frameworks?

In accordance to Greca and Moreira (2003), we point out some commonalities in these two theories, which have guided this research project and have brought about relevant issues in its methodological implementation with the teachers, such as:

- A biological conception of the cognitive process: Johnson-Laird (op.cit) assumes that our world experience is a consequence of *natural selection*, while Vergnaud (op.cit.) uses the Piagetian concept of *adaptation* as a way of generating knowledge. Natural selection and adaptation are

biological concepts applied, in both instances, to mental processes and are linked to the concept of evolution.

- Both authors maintain critical views on the Piagetian idea that reduces explanations of cognitive functioning to logical rules, and the two of them attribute to the contents of knowledge itself a crucial role in the individual's conceptual development.
- They also share ideas about the role of representations as an interface between the subject and reality. Actually, Johnson-Laird (op.cit.) believes that the human mind represents the world and it does so by means of a threefold code: propositions, images, and mental models. Vergnaud (op.cit.) states that knowledge construction comprises a progressive construction of explicit or implicit mental representations that are homomorphic to reality in some aspects but not in others.
- These authors emphasize the role played by concepts and their construction. Johnson-Laird holds that there is a hierarchical organization in the person's conceptual structure from which it is possible to get to the conceptual primitives. Vergnaud asserts that concepts are pivotal for comprehension and necessary in the search for solutions to concrete situations.

3 Research methodology

The methodological focus is mostly of descriptive and interpretative characteristics in agreement with the aims of this research. The research sample comprised teachers who attended academic activities offered by the Planetarium of Barranquilla, Colombia. Data from diverse sources were analyzed according to the following parameters: *concepts involved and linkages established among them; theoretical issues handled by the subjects in the explanation of situations and phenomena; stability or permanency of the models in time and along a variety of situations*.

The concept maps, which were interpreted here according to the theories that underlie this research, refer to the five teachers (identified by JC, RG, OM, JG, and AF). Although we will not analyze the totality of instances due to the scope of this paper, this does not prevent us from reaching some conclusive considerations which support the use of concept maps as instruments to bring about the teachers' representations of models of the universe and their evolution by means of a mediation offered by a teacher, in this case the researcher him/herself.

4 Descriptive analysis of the teachers' concept maps about cosmological models

Concept maps are diagrams that indicate relationships among concepts. They can be seen as hierarchical diagrams that reflect the conceptual organization of a body of knowledge, or part of it (Novak, 1998; Moreira, 2006). According to these ideas, we have privileged in their interpretation the conceptual structure they presented, taking into account the elements included as concepts and the linkages established between and among these concepts.

Concept maps and their descriptions, developed during the activity sessions attended by this group of teachers at the Planetarium, in Barranquilla, Colombia, are presented here. We analyze the sequence of maps drawn by teachers JG and AJ as evidences for the validity of this instrument and also to inquire about how it can allow us to infer the evolution of the teachers' representations of the universe when a conceptual enrichment is provided in the activities offered in the Planetarium.

4.1 Concept maps of teacher JG.

The first map was drawn and presented in a group session in which the teacher himself explains and justifies its elements and linkages. We can infer that, according to the concepts and linkages it contains, this teacher holds an origin for the universe in which it transforms itself, evolves and expands itself both in time and in space. This process, according to this teacher's cosmological conception, makes possible the formation of matter and energy and the generation of forces. Figure 1 shows JG's first concept map. These maps are shown in its original form and they have not been corrected to respect the teachers' own representations considering that their quality expresses the content of the teachers' knowledge.

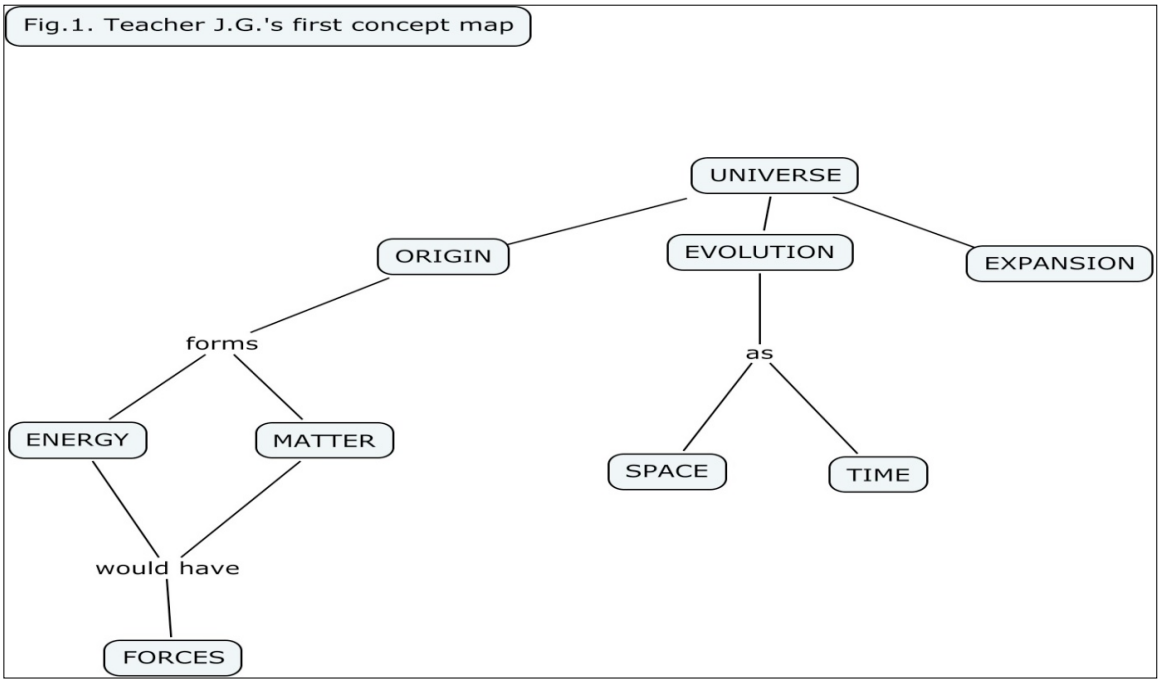

Figure 1. Teacher J.G.'s first concept map.

The second and the third maps drawn by the same teacher express more clearly ideas related to a conception of the universe that seems closer to the standard cosmological model. We can notice in them a greater number of conceptual elements that show better linkages among them than the first one. We stress that both the first and the second maps were drawn in one of the meetings with the teachers at the Planetarium, whereas the third one was not drawn within the formative spaces of the Planetarium. Figure 2 and 3 depict these representations about the universe drawn by teacher JG.

The first assessment they might offer us concerns the conceptual development experienced by this teacher throughout his consecutive maps. The analysis of teacher JG's concept maps allows us to convey that these maps can be indications of an evolutionary process in the representations JG holds about cosmological models, expressing the presence of new concepts in his cognitive structure that have enriched his representation of the universe.

According to the theories that underlie this research, the fact that the new information managed to get structured in the mind would point out that more stable mental models have been formed, which emerge when a person is faced with new situations and evolve towards conceptual schemas for the universe because of their functionality. Nevertheless, if we want to confirm these hypotheses new steps and activities are required since conceptualization processes are progressive and extensive.

4.2 Teacher AF's Concept maps

Figures 4 and 5 show Teacher AF's concept maps whose analysis might allow for some inference about the evolutionary process of conceptualization during the activity sessions in the Planetarium.

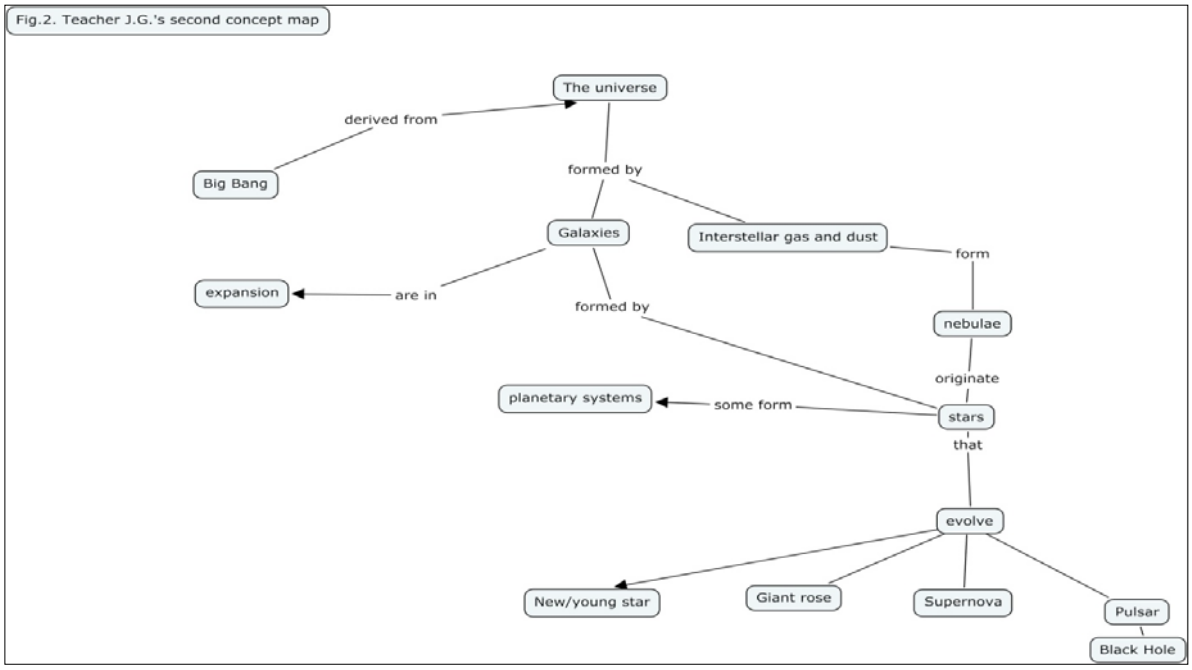

Figure 2. Teacher J.G.'s second concept map.

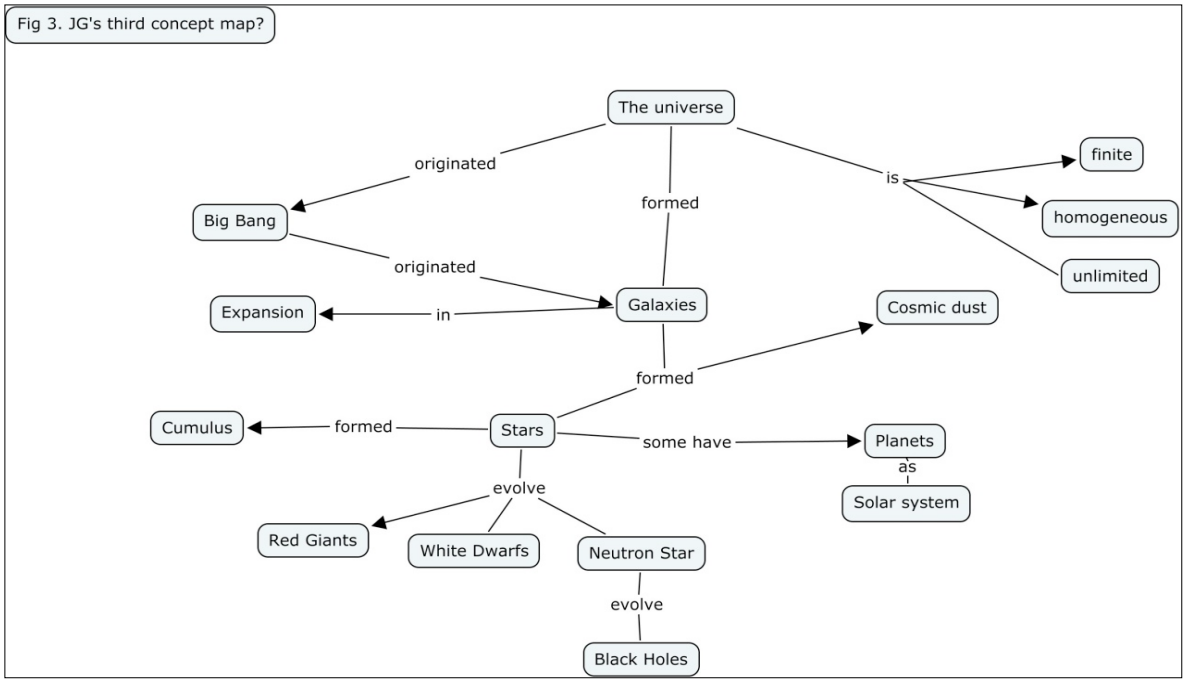

Figure 3. J.G.'s third concept map

It is possible to notice in teacher AF's concept maps that his second map is a complementation of the first one since both refer to the origin and constitution of the universe based on the standard cosmological model, although it includes elements that are part of modern scientific theories. The teacher himself stated that *the readings done have allowed him to add elements he had already incorporated to his cognitive structure when the understanding of linkages among these elements became clearer*. We can notice a progressive conceptual evolution concerning his initial representation of the universe.

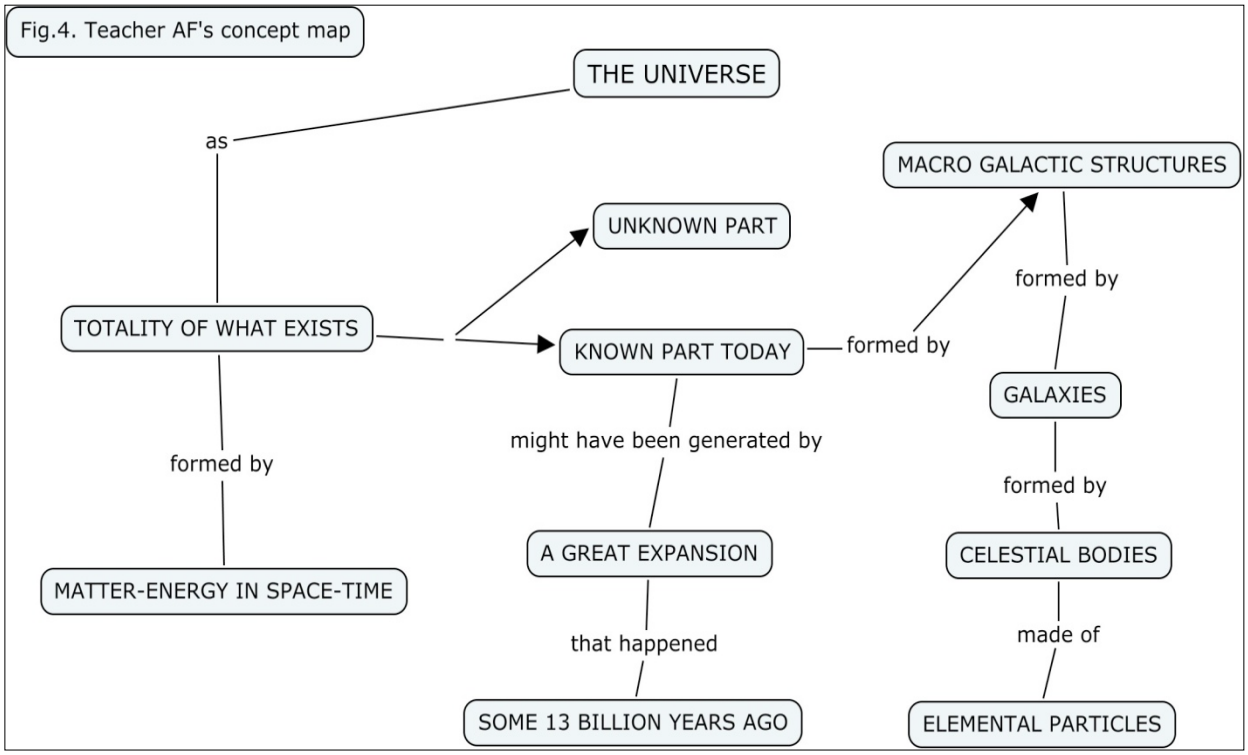

Figure 4. Teacher A.F.'s first concept map.

5 Summary

Although for reasons related to the limitation of length of this paper concept maps drawn by just two of the teachers have been presented here, we can consider them as indicators of the representations of the sample of teachers in this research, and this can lead us to bring to discussion some elements about the potential of concept mapping as an instrument to make explicit the knowledge these teachers had in their cognitive structure about models of the universe. The concept maps shown here might be considered to have a reasonable approximation to the representations hold by these teachers in their cognitive structure, though not particularly precise or complete (Moreira, 2006). Concept maps are suitable instruments to visualize concepts and their relationships with other concepts available in the person's cognitive structure, thus, allowing for the construction of new meanings in a given field of knowledge.

Comparative analysis of the concept maps of the teachers who participated in the Planetarium activity sessions suggests that the elements and linkages established among them can indicate a difference in the conceptual clarity of their representations. Mental models can be viewed as functional knowledge since they can reveal the degree of comprehension that a person has about an event, a situation, or of a system, and how and why it works that way, so we have to agree that the education in sciences offered to students in different levels of schooling, in Colombia, might not allow them to develop scientifically accepted mental models and/or conceptual schemes about the universe. Consequently, there is a need to promote educational policies to improve science education so as to grant teachers in all educational levels the opportunity to anchor scientific (in reference here to cosmology) knowledge in their mental structure. Johnson-Laird (1983) states that more complete and coherent relations imply better perceptions and visualizations.

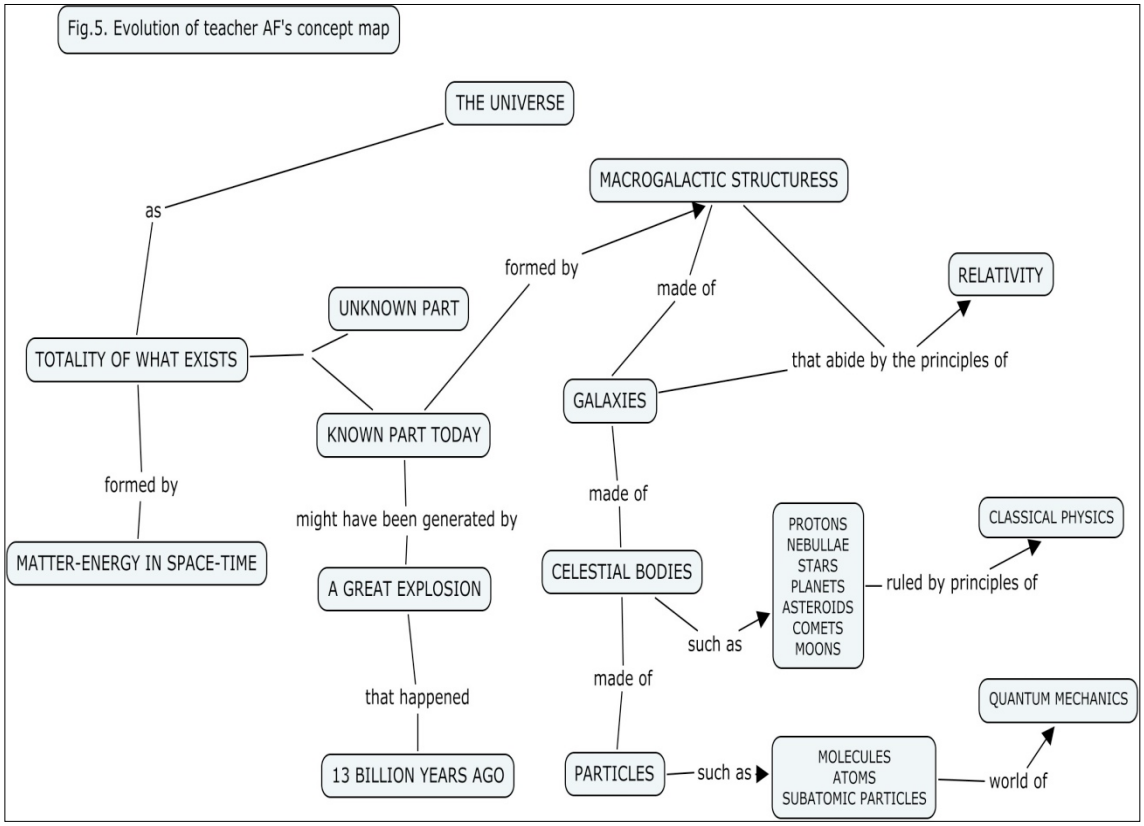

Figure 5. Teacher A.F.'s second concept map.

We also compared concept maps when there was a diversity in the teachers' educational background, since they all had a teaching degree (Licenciature) but have majored in different areas of knowledge, such as social sciences, biology, and chemistry. There are representations that differ in their conceptual content, and this might lead us to suppose that beyond the individuals' vocational formation, in their external representations of the universe there are elements that indicate and determine the structure of the representations these persons develop which may not derive from the formal education they have received.

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