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LOGICAL SYSTEMS AND NATURAL LOGIC: CONCEPT MAPPING TO FOLLOW UP THE CONCEPTUALIZATION PROCESSES

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Abstract. The concept maps built and shared in the internet through the CmapTools resources were used in this study to follow and to analyze the processes of concept construction in the school learning situations. The samples, from a Brazilian public school, built maps in the context of learning projects developed in a digital environment. Jean Piaget's Genetic Psychology and Epistemology, which supports the project method in use in the net environment, was chosen as a methodological-theoretical alternative to Joseph Novak's proposal that uses David Ausubel's Meaningful Learning. Moreover, we made use of Jean-Blaise Grize's Natural Logic to build the data analyses in natural language, comparing them with the evolution and modifications of the linking phrases in the concept maps.

1 Introduction

In the literature as well as and in meetings related to the new technologies and education, like the International Conference on Concept Mapping and the Brazilian Symposium on Informatics in Education, the growth of scientific production and the educators' interest on the use of concept maps became evident, especially for learning improvement and managing and organizing knowledge.

Through this resource we, researchers and teachers, are not looking for the punctual evaluation of the individuals' performances, but to the possibility of analyzing the development of their cognitive mechanisms throughout the evolution of the mapping sequence, created in their learning process. In general, the analysis criteria presented are quantitative (number of relevant concepts, counting of the correct propositions, etc.), or produce comparisons of the students' concept maps with the specialists´ (or teacher´s) maps to suggest the substitution of the propositions which are considered incorrect (Ahlberg et al. 2004; Conlon, 2004; Cunha et al. 2004; Rocha & Favero, 2004a and 2004b).

The foundations of the Genetic Psychology, in the body of Jean Piaget's Epistemology, explain the process of concept construction as a gradual and interactive dialogue between the individual´s logic systems and systems of meaning. The existing methods used for the evaluation of concept maps seem to be unable to encompass this kind of thinking about cognitive processes. In this article, we will briefly discuss an adaptation of Piaget´s take on learning to the concept maps, and propose a analysis model of conceptualization based on this perspective.

2 Concept Maps and Piaget´s Theory

Novak (1998) defines a concept map as a tool to organize and to represent knowledge. The concept map, supported by David Ausubel's (2000) meaningful learning theory is a graphic representation in two dimensions of a set of concepts built in a way that the relationship among them are evident. Two or more concepts, connected by linking phrases, create a semantic unit called proposition. The propositions are a particular form of concept maps in comparison to other types of communication. This is, precisely, the characteristic that favors our study, which strives for a new interpretation of this type of representation. We are not, however, proposing a substitution for Novak's contribution. Our goal is to add a more specific knowledge, which helps to analyze and to understand the cognitive mechanisms under a more systemic focus.

An evident fact is that the relationships in a concept map are established in language, that is, the words chosen by the author of the map represent the concepts and the respective linking phrases. It is interesting, however, to note that Piaget showed that the construction of meanings occurs even before the language acquisition (Piaget & Inhelder, 1976). Besides, the construction of a logic which organizes the subject's systems of meaning happens simultaneously at the beginning of his interactions with the knowledge objects (Piaget, 1996). At the beginning, this logic organizes the objects directly in the action (in this case, in the physical world, that is, to push, to grab, to put in

the mouth etc.). When these actions are performed through representations (semiotic function), and it becomes possible to use language, these systems of meaning can be evoked in the subject's discourse.

Ausubel (2000) defines concept as a perceived regularity in events or objects in a way that they and the propositions are the construction blocks of knowledge in any domain. This perspective implies in believing that the perceptive mechanisms are the means by which the concepts are acquired by the subject. For Piaget, however, the concepts are built from successive levels of awareness states which allow the subject to "internalize" actions and produce transformations (from a simple reconstitution of facts to reversible transformations, that is, operations) in the objects in thoughts (Piaget & Inhelder, 1976).This way, when establishing judgments, the individual *acts* over the concepts establishing relationships among them, or applying them on determined objects (Piaget, 1976). Regarding the language, a predication is required when establishing a judgement. Consequently, the establishment of relationships between concepts cannot be without verbs. With this perspective in mind, we state that, in addition to Novak's definitions, the presence of verbs in the linking phrases is an essential condition for a concept map.

For Piaget, each new concept is built by assimilation stages and consequent successive accommodations of new meanings. Each stage combines the previous ones, maintaining elements and relationships non-conflicting with the real state of the system (in the case of successful adaptations) and modifying (and not simply reorganizing or substituting) those elements and relationships that, due to a necessity of the action (of its means and objectives) or the transformations and operations in thought, became disturbances. About this, Piaget states that "a conceptual system, indeed, is such a system that its elements inevitably lean on each other, being at the same type open to all exchanges with the exterior. We can suppose the construction of an only concept A, as a classification starting point, etc. If it is really a concept, then it is already opposed to a non-A concept, which establishes a total and circular system since the first moment. In the case of a multi-conceptual system, it is impossible to characterize any concept without using others, in a process which is also necessarily circular" (Piaget, 1976).

A conceptual system characterized in this way is comparable to a structure, a theoretical construct extremely important for Piaget. According to him, the structure is the condition for possible knowledge. Shortly, we can say that a structure (particularly the cognitive structure): (a) contains elements and relationships which connect them without, however, being able to define such elements independently of the relationships; (b) can be considered independently of the elements which are part of it, that is, when abstracting the elements, it is possible to consider a relationship system or a structure "form"; (c) evolves from more elementary types up to the high order ones as the elementary structure becomes elements of higher order structures; (d) can be compared to another structure if it is possible to define an isomorphism which places each one of its elements in biunivocal correspondence and, respectively, each relationship which gathers them, in a way that the meaning of such relationships is preserved; and (e) contains sectors or parts called substructures which, depending on the relationship system that are part of them, may or may not present an isomorphism in relation to the structure as a whole (fractal) (Piaget, 1996).

3 Piaget´s logic

According to Piaget (1976), knowledge evolves to structure itself in systems of propositions, interdependent and dynamic. In higher levels, thinking would happen, therefore, through logic operations in the systems. The central idea is that the formalization (of relationship systems) is not stale, but a process, and it supports itself in dynamic structures. To state something is to operate with systems of meanings, and not only to draw from previously acquired (and complete) knowledge. Therefore, in a piagetian perspective, an important aspect in the analysis of cognitive processes is to observe these kinds of actions, or judgements, established by the individuals in their discourses. One of the "tools" for such thing is propositional analysis.

A proposition is a statement susceptible to qualification. That is, a proposition must have a meaning, so that it can be evaluated as true or false. This is important because, as expressed before, this type of representation allows for the observer to have a clearer evidence of the relationships established between concepts. Besides, the relationships established between different propositions (interpropositional operations) can also be analyzed, as well as operations inside a proposition itself (intrapropositional operations). A proposition is one of the ways in which the individual can structure his thoughts, and redefine them. Thus, propositional analysis is an important way of observing the conceptual relationships and their implications in one´s discourse.

For Piaget (Piaget & Garcia, 1989), there are implications between meanings from the more elemental levels of thought. In the case of the construction of concept maps, when we choose a relationship between two concepts (expressed by a linking phrase) we are performing a *meaning implication*. This piagetian construct, in short, is a way to look at the relationship between meanings established by the individual, and to analyze them in levels. These levels are the results of the development of structures which allow the subject, from a long process of construction of logic relationships (due to the situations faced by him), to expand his comprehension about the knowledge objects. This way, Piaget states that there is a Logic of Meanings which precedes the Formal Logic and that from the child's action up to his operations in thought there is a correspondence between the formal operations and the meaning implications. What happens is that the formal operations are sufficiently differentiated to allow its combination in a set system. In the case of the meaning implications, it is possible to observe the same formal operations performed in very particular contexts without, however, being necessarily general or applicable in other contexts.

In the following paragraphs, we will present an adaptation (Dutra, Fagundes & Cañas, 2004) of the meaning implication theory aimed at analyzing the concept maps, with special emphasis on the linking phrases. These criteria adapted from Piaget's theory allow not only for a more global analysis of the maps (or the subsystems emphasized in them) but also an analysis of the types of logic operations of thought involved in the isolated propositions or in their combinations.

A **local implication** can be defined as the result of a direct observation, that is, what can be registered of the object through observation of its context and its attributes. In a way, a local implication can characterize an object without, however, updating the knowledge about it. In a concept map, the local implications generally appear in the propositions with linking sentences which use verbs like "is", "has" etc.

A **systemic implication** inserts the implications in a system of relationships in which some generalizations and properties not directly observable start to appear. In this sense, the differentiations are not only perceived from qualities of the object, but inferred from it or from the action over it. In the maps we can perceive relationship systems (generally hierarchic) where there are implications between the concepts that, while not giving explanations or justifications, take into account some causes and consequences. Relationships between events and objects are established, but questions like "how?" and "why?" remain unanswered.

A **structural implication** broadens the previous ones because, here, the reasons and the "whys" show up. Piaget mentions that his level of implication is the comprehension of reasons and the discovery of the necessary relationships (Piaget & Garcia, 1989). Thus, more than knowing causes and consequences, the structural implications establish that conditions (in the logic sense) are essential for certain statements, in contrast to merely sufficient ones. In the case of the concept maps, we would have to combine a set of propositions so that we can have structural implications.

4 Natural Logic

Collaborating with Piaget for many years, Jean-Blaise Grize proposed to provide a model of discursive scheme analysis, that is, a content logic. In this sense, the Natural Logic consists of a model which deals with the common thought (non scientific) and, in this way, allows an exploration of the aspects related to the aspects of discourse which are not, in a way, objects of Piaget's model. The advantage of using such tool is to have a theoretical approach which deals with the cognition from corpus formed directly in the written or spoken language. For Grize (1996), the natural logic can only emphasize the aspects of the objects and the predicates that appear in the discourses. Based on this, he built a model which allows us to observe the building and determination of objects, and the operations used by the individual in order to achieve this. As the natural logic is an important part of our analysis model, we will describe some of these discursive operations.

When we speak of a class-object (a theoretical construct that could be loosely compared to a concept), the elements which are part of them are like ingredients and belong to what is called *bundle of the class-object*. Such elements can be introduced one after the other in the class-object through a family of operations (**operations over the bundles**) where four types are distinguished: to introduce a part of the object; to mark an internal process to the

object; to mark the object state, one of its ways of appearing or one of its qualities; and finally, to mark a dimension, a plurality, an extension.

The **retake operations** designate an operation family which is used to call the same object in another way. That is: introducing a term of close type (table ->furniture); presenting the object in another angle (metonymy) (bridge -> Golden Gate); establishing a judgement of value (father -> my hero); or emptying an object of its content (my computer -> this guy).

As for the **localization operation,** when it is applied to the judgement contents, it implies in localization in space, in time or even relative to other elements. For example, a statement like The Republic President is elected for seven years, cannot be taken as true or false unless in a certain country and in a given time in history.

According to Grize (1996), the mathematical logic is not concerned with the assertive subject. It makes the true and the false be in the nature of things as if the propositions were given. For him the natural logic cannot satisfy itself viewing this. Thus, the natural logic is not only object logic but equally a subject logic, more precisely the one with subject announcers who engage, assume a determination and interpret it. We will now briefly emphasize the discourse operations which refer to the subject enunciator.

The **turn polioperation** is an operation that, when applied in a judgement content, does not produce a simple proposition, but an expression, marking: (a) the enunciator subject (I, somebody, the scientist etc.); (b) its thought activity (to say, to believe, etc); (c) its time-space localization; and (d) a modality *de dicto* (establishing a judgement that the enunciator makes of what he refers to).

It is called **configuration** the structure of statements that gives meaning to the relationships between them. The configuration reflects the representation structure that the enunciator shows. In this sense, the mathematics formal logic connectors are used to establish an order for the different enunciations.

1 Method

In order to analyze the conceptualization process, we decided to perform a case study with 7 children (ages 10-12) from a public school in Brazil. The study was based in accompanying and helping the development of a research project of their own, based on a question they chose. For this, we had bi-weekly meetings, 2 hours and a half long, in which the children were able to research and write about their work. We asked them to build concept maps at the beginning of their projects, and then periodically (in a somewhat regular interval) review and update those maps in light of their research progress. In total, there were 25 meetings, and each participant was able to build 5 versions of their concept maps.

The data was obtained from the concept maps, and from the text written by the individuals in digital means: (a) in blogs- virtual agendas; (b) in the digital conceptual maps (built in CmapTools software), saved and shared in the internet in a server; and (c) in a wiki, an online system of electronic editing of internet pages. Moreover, the researchers made interviews (using Piaget's clinical method) after each different versions of the concept maps built by the subjects. Not only the data, but also the analysis performed are being organized in a digital database, projected and implemented in order to allow future studies to validate the model we now present.

Our follow up proposal of the conceptualization processes consists of the analyses of the logic operations (interpropositional operations, meaning implication levels and discursive logic operations), of a temporal series of data of the same subject which include speeches in natural language (obtained from the stored texts in the blog or in the wiki, as well as the transcription of the interview performed regarding the concept mappings) and propositions and systems of explicit relationships in the different versions of the concept maps that were built.. We will now demonstrate the application of the follow up model using the data of a single youngster: HEN (12 years old), whose research question was "how does a motorcycle engine work?". All the data presented refer to the speeches, written text and concept maps of HEN. The excerpts in italics are the original transcripts of such data.

5 Results

08/23/2005, interview – HEN [About the movement of the motorcycle]: *But there is a part that is in the engine, for example, like this, I don't know where it is, that I think makes it run. Put some gas, it is the food of that stuff, it would be a…some gears, it starts to spin like a bike peddle, so it would give power* [for the engine to run].

The first part, a transcript of HEN's speech on the first day of the project activities, reveals the available system of meanings regarding his hypotheses about the functioning of a motorcycle engine. In this extract, the same class-object is denominated part, stuff and then gear (retake operation). The logic-discursive operations, according to the configuration established by the subject, account for: locating the part in the engine (even though not precisely); marking the qualities of such part (to make the motor run - operation over the bundle); establishing a metaphor (gasoline -> food); and revealing the enunciator's thought operation (I think). Regarding the logical propositions effectively expressed, we initially have that "the part makes the engine run". There is an indication that the gasoline is responsible for the spinning of the referred part and that this movement implies in the necessary strength for the engine to run. But that still doesn't reflect a coordinated set of propositions, as the relationship system detailed by HEN in his first map (Figure 1), made using CmapTools software (Cañas et al. 1999; Cañas et al. 2004), has revealed.

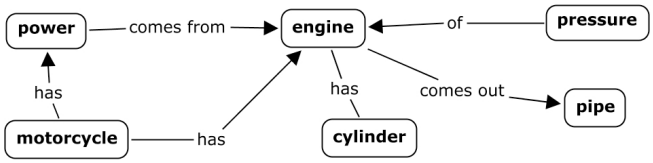

Figure 1. Part of the first concept map constructed by HEN on August 30, 2005.

In HEN's first attempt to formalize a representation of his knowledge, we observe a logical system that can be characterized as composed of local implications. The concept map describes the concepts that appear there based on its attributes (pressure of engine), components (engine has cylinder) or characteristics (power comes from engine). However, we can already observe that HEN, by an operation expressed in the combination of propositions, seems to indicate that the functioning of a certain system - the engine - results in the attribution of a 'new' characteristic to another system – motorcycle - to which the first one is subordinated (by a logic fitting): the motorcycle has power that comes from the engine. Is this a first sketch of systemic implications?

09/06/2005, interview - HEN: *You put gas (…) Makes, starts combustion, starts to burn, so with this burning there is pressure, this pressure goes to the cylinder, lowers the thing that I don't remember the name, so the…a kind of gear comes down and makes a crown comes up, let's say, like a bicycle, so in this crown there is a chain tied to the wheel, so with the spin of this crown the wheel starts to spin and the motorcycle starts to run.*

In general, the configuration of this excerpt doesn't establish internal elaborations to classes-objects. The disposal of statements reveals a sequence of events (a functioning explanation), and the final result is the motorcycle movement. It is interesting to observe that HEN, when reflecting about his work in the map, brings new elements (new concepts: cylinder, combustion, crown, etc.) and inserts them in the discourse to the determinations already expressed previously (like: 09/06 - a kind of gear comes down and makes a crown comes up, let's say, type of bicycle…←→ 08/23 - some gears, it starts to spin like a bike peddle, so it would give strength). His new elaborations will only show up (and partially) in the second version of the map (figure 2).

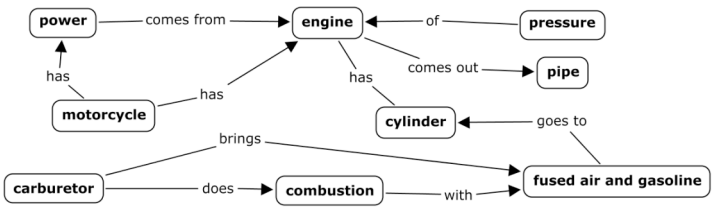

Figure 2. Part of HEN's second concept map, constructed on September 27, 2005.

The local implications of the first map now give place to a better differentiated system. We had already noticed, in our field agenda, on 09/09/2005 that HEN seemed to have reached the conclusion that it is necessary to have gas, the air and the sparkle produced by the spark plug (engine part) to have explosion. Our note, plus the previous excerpt of HEN's explanation about the first map, seems to be expressed by him in this sequence of propositions: "Carburetor brings fused air and gasoline, carburetor does combustion with fused air and gasoline, and fused air and gasoline goes to the cylinder". This novelty in the system provides more concrete evidences that HEN starts to make compositions between the propositions. Moreover, the links established by him expressed, besides the directly perceived observables, some cause and consequence relationships, as well as properties deducted from objects or actions (in thought) about them. Therefore, according to our classification, we have evidences of systemic implication systems.

10/04/2005, blog – HEN: *What is a carburetor? The carburetor is one of the most important parts of the engine, that's where the air meets the gasoline, and through this, the spark plug releases an electric discharge and with this discharge it gets on fire and explodes. What is spark plug (engine)? The spark plug is in the carburetor, it makes sparkles and with the sparkles, the explosion (combustion). What is explosion? Explosion is the same as combustion. And the explosion is formed by the fusion of gasoline and air. What is gasoline? The gasoline is a fuel that makes part of the combustion. What is a piston? It is a part that goes inside the cylinder. It is used to give pressure to the engine.*

This excerpt shows a new discursive elaboration by HEN, which results mainly from the examination of the second version of his concept map, as well as of the previous writings in the blog or wiki. Of importance here, to the logic-discursive operations, is the judgement of value (relevance criteria) of what is expressed: *carburetor is one of the most important parts of the engine*. The configuration shows a certain concern expressed by HEN in explaining recursively each term that appears in his text.

The last two concept maps that we are going to present and to discuss were constructed during the same day. For the construction of the first one, HEN followed strictly the method used in the previous versions: after a period of researching and discussing with his teachers and peers, he proceeded to the review of the last version available of his map and made all the modifications that he judged necessary. As it can be observed by the dates of each previous map, this period was approximately 30 days. The second map, however, resulted from the interventions done by an interviewer, during the clinical interview regarding the first section map (figure 3).

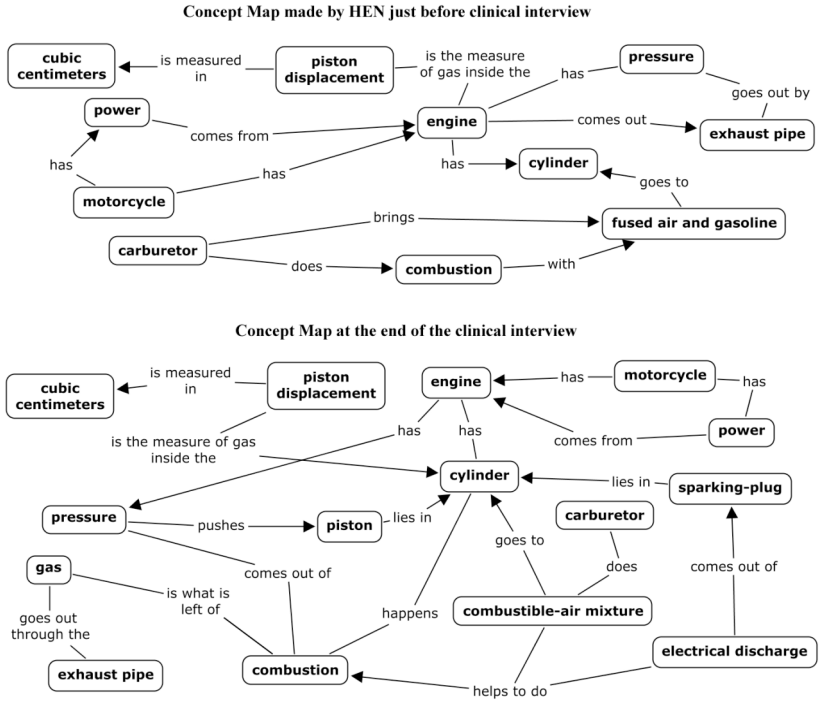

Figure 3. HEN's concept maps, constructed on November 4, 2005.

The first map of the figure 3, if compared to the previous version (Figure 2), reveals the modification on the phrase "pressure of engine, which is now "engine has pressure". That is, the pressure is no longer considered a motor quality to become a property, being incorporated to the domain of the motor functioning. It is also noteworthy that the differentiation of the "pipe" concept, which now appears as "exhaust pipe". The novelty is the presence of the propositions "piston displacement is the measure of the gas inside the engine", and "piston displacement is measured in cubic centimeters". This relationship system is still in the level of systemic implications. When we contrast the two maps of Figure 3, however, we notice that HEN has produced modifications in order to provide reasons and justifications. Or, as we said previously, he took steps towards answering questions like "how?" and "why?".

The strategy of this particular clinical interview consisted in asking for explanations regarding the relationships that appeared in the map at the beginning of the section. Immediately after each explanation given by Hen, he was asked to judge if his explanation could produce some kind of modification in the map and, if the answer was affirmative, he was encouraged to register it on his map (resulting on the second map of figure 3).

11/04/2005, interview- [What is this pressure?] HEN: *This pressure would be: the gases which were formed with the explosion, plus the gases which were not used for combustion. Because the oxygen and other gases get in and leave through the exhaust pipe. The explosion causes the pressure, which would be, let's say, a large volume of air that makes the cylinder move.* [How does that explosion occur?] HEN: *an electric discharge by the spark-plug so there is an explosion, and with this explosion there will be pressure, because it will push the cylinder. Because if there wasn't for that explosion, the cylinder wouldn't go down. (…) Combustion makes pressure.*

The configuration of the excerpt above shows a complex elaboration of the classes-object (not only internally, but in relation to other classes). Now, not only does HEN expresses the cause and consequence relationships, he already builds statements, and is able to build propositions that indicate a logic necessity: *"if there was not that explosion, the piston wouldn't go down"*. Indeed, the explanation given by HEN provoked the following modifications in the first concept map: (a) the concept "piston" was finally included, as well as the concepts "sparking-plug", "electrical discharge" and "gas"; (b) propositions were added, like "pressure pushes piston", "piston lies in cylinder", "pressure comes out of combustion", "electrical discharge comes out of sparking-plug", "gas is what is left of combustion" and "gas goes out through exhaust pipe".

At last, the following passage seems to reveal that HEN is effectively making logical operations with the propositions: *"potency and piston displacement …the relation is that they measure something. The piston displacement measures the size of the cylinder and potency measures the engine power. They serve to measure things (…). The engine potency comes from the cylinder and what measures the cylinder is the piston displacement, so we say that there is a chain, right? It has a cycle*". Based on our criteria, he seems to be able to operate with conditions and justifications in the context of his research theme. We conclude, therefore, that there are evidences of structural implications at this stage of HEN´s discourse.

6 Summary

In contrast with a written text, the concept map seems to reveal itself more fertile in possibilities, in the sense of a more faithful expression of the system of meanings of an individual. In addition, it can be an excellent support device to conceptual construction and revision, as its structure allows for a different way to represent knowledge. It is important to remember, however, the dialectic aspect involving the two types of representation that we are analyzing: concept map and discourse in natural language. The construction of concept maps gives the opportunity to grasp levels of awareness, which influence the discourse configurations in natural language. In turn, the successive construction of discourses provides new elements for inferences, which can allow some new proposition combinations in the concept maps.

In this article, we presented and discussed the implementation of an analysis model which aims to follow up the conceptualization process through the analysis of natural language and periodically built concept maps. Based on theoretical constructs such as the *meaning implications* theory of Jean Piaget and Jean-Blaise Grize´s work in the analysis of *natural language*, we were able to produce results of the utilization of such model. The case presented here shows the conceptual differentiations established by an individual throughout his research project. We showed

that our analysis was able to identify evidences of his progress, based not only on the propositions expressed in his maps, but also on his speech and written text. In that way, we emphasize the relevance of taking into account these different types of data, and the longitudinal aspect of our study.

We believe that our theoretical approach, based on Jean Piaget´s Epistemology, provides a novel way to look at concept maps and its use as tools for learning evaluation. The analysis model presented here is a contribution for more deepened discussions, and aims to allow possible applications in the educational use of the concept maps. It is our intention to continue the investigation, as well as to establish partnerships in order to validate our analysis model.

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