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A process model to looking for signs of learning using concept maps: a case study

Título: Um modelo de processo para procurar indícios de aprendizagem usando mapas conceituais: um estudo de caso

Título: Un modelo de proceso para buscar señales de aprendizaje mediante mapas conceptuales: un estudio de caso

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Abstract

Concept maps are pedagogical tools widely used to facilitate the teaching and learning process. They are an important instrument for learning assessment including aspects of Ausubel's theory that defines the principles of meaningful learning. Assessment of learning through concept maps are proposed in several works in the literature considering structural and semantic analysis. However, certain learner's cognitive aspects are only observed during the construction of concept maps. Therefore, analyse the maps construction process is essential to improve learning assessment through concept maps. One of the contributions of this paper is to present an evaluation process model which considers a set of efective criteria defined from maps individual propositions, aiming to point out signs of learning, classified as non-learning, rote learning and meaningful learning signs, through a detailed analysis of both maps and maps construction process. The evaluation process can be automated in order to give support for education. We evaluated our process model using a case study that, besides identifying signs from structural and semantics analysis, explore new learning signs from maps construction process. This paper mainly concentrates in the case study exposition and for that it uses a systematic presentation of the map evaluation process model. As the best as we know, our proposal differs from the works in the literature mainly due to the analysis of maps construction process combined with syntatic and semantics analysis of maps to identify signs of learning.
Keywords: *Concept maps; Meaningful learning; Map evaluation; Process of maps construction.*

Resumo

Mapas conceituais são ferramentas pedagógicas amplamente utilizadas para facilitar o processo de ensino e aprendizagem. Eles são um instrumento importante para avaliação da aprendizagem, incluindo aspectos da teoria de Ausubel que define os princípios da aprendizagem significativa. A avaliação da aprendizagem por meio de mapas conceituais é proposta em vários trabalhos na literatura considerando análise estrutural e semântica. No entanto, certos aspectos cognitivos do aprendiz são observados apenas durante a construção de mapas. Portanto, analisar o processo de construção é essencial para melhorar a avaliação da aprendizagem por meio de mapas conceituais. Uma das contribuições deste artigo é apresentar um modelo de processo de avaliação que considera um conjunto de critérios efetivos definidos a partir de proposições individuais nos mapas, visando apontar indícios de aprendizagem. Os indícios são classificados como indícios de não aprendizagem, de aprendizagem mecânica e de aprendizagem significativa, por meio de uma análise detalhada de mapas e dos processos de construção. O processo de avaliação pode ser automatizado para dar suporte à educação. Nosso modelo de processo é avaliado com um estudo de caso que, além de identificar indícios de aprendizagem a partir da análise estrutural e semântica, explora novos indícios de aprendizagem através do processo de construção de mapas. Este artigo se concentra principalmente na exploração

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do estudo de caso utilizando uma apresentação sistemática do processo de avaliação de mapas. Até onde sabemos, nossa proposta difere dos trabalhos da literatura principalmente pela análise do processo de construção de mapas combinada com análise sintática e semântica para identificar indícios de aprendizagem.
Palavras-chave: *Mapas conceituais; Aprendizagem significativa; Avaliação de mapas; Processo de construção de mapas.*

Resumen
Los mapas conceptuales son herramientas pedagógicas ampliamente utilizadas para facilitar el proceso de enseñanza y aprendizaje. Son un instrumento importante para evaluar el aprendizaje, incluyendo aspectos de la teoría de Ausubel que define los principios del aprendizaje significativo. La evaluación del aprendizaje a través de mapas conceptuales es propuesta en varios trabajos de la literatura considerando el análisis estructural y semántico. Sin embargo, ciertos aspectos cognitivos del alumno sólo se observan durante la construcción de mapas conceptuales. Por tanto, analizar el proceso de construcción de mapas es fundamental para mejorar la evaluación del aprendizaje a través de mapas conceptuales. Uno de los aportes de este artículo es presentar un modelo de proceso de evaluación que considera un conjunto de criterios efectivos definidos a partir de proposiciones individuales de mapas, con el objetivo de señalar indicios de aprendizaje, clasificadas en indicios de no aprendizaje, aprendizaje mecánico y aprendizaje significativo, a través de un análisis detallado de los mapas y su proceso de construcción. El proceso de evaluación se puede automatizar para apoyar la educación. Evaluamos nuestro modelo de proceso utilizando un estudio de caso que, además de identificar indicios de aprendizaje a partir del análisis estructural y semántico, explora nuevos indicios de aprendizaje a través del proceso de construcción de mapas. Este artículo se concentra principalmente en explorar el estudio de caso y para ello utiliza una presentación sistemática del modelo del proceso de evaluación de mapas. Hasta donde sabemos, nuestra propuesta difiere de trabajos en la literatura principalmente por el análisis del proceso de construcción de mapas combinado con el análisis sintáctico y semántico de mapas para identificar indicios de aprendizaje.
Palabras clave: *Mapas conceptuales; Aprendizaje significativo; Evaluación de mapas; Proceso de construcción del mapa.*

1 Introduction

Learning assessment is a complex process which requires the creation of mechanisms to verify possible changes in the learner's cognitive structure while providing information about acquisition of knowledge. Assessment should also be used to promote learning, allowing an analysis about knowledge and cognitive abilities acquired by the learner and, thus, enabling the teacher to act on unlearned knowledge, changing teaching methods and contents, in order to promote a more qualitative teaching in the learning process (da Silva & Omar, 2017).

Aware of this, J. D. Novak and Gowin (1984) developed a pedagogical tool called a *Concept Map - CM*, used to facilitate the learning process, an important instrument for the structured representation of knowledge. According to J. D. Novak (1998), a CM can represent part of a person's cognitive structure, revealing his/her particular understanding of a specific knowledge area, bringing advantages for the assessment of learning. CMs are widely used as an instrument to facilitate the process of meaningful learning assessment (J. D. Novak & Gowin, 1984).

Meaningful learning is a process through which new information is substantively and not arbitrarily related to a relevant aspect of the learner's cognitive structure. According to Ausubel (2000), meaningful learning presupposes organization and interaction of information in the learner's cognitive structure, as opposed to *rote learning* in which new information is stored in an arbitrary way, with little or no association of relevant concepts in the knowledge cognitive structure. As meaningful learning occurs, concepts are developed, elaborated and assimilated through the cognitive processes of progressive differentiation and integrative reconciliation. Progressive differentiation occurs when a new concept is incorporated in the learner's cognitive structure, and integrative reconciliation when an association is made between already introduced concepts in order to acquire a new meaning.

Although CMs can help in teaching-learning and assessment processes, there are important challenges when we aim to carry out learning assessment using them. One of these challenges is the different cognitive constructions of knowledge, either due to the intrinsic nature of the cognitive processes (inherent in each person), or due to the number of students under assessment, which can make the learning assessment activity difficult (J. D. Novak & Gowin, 1984).

Researches in the area of Informatics in Education (Anohina et al., 2007; Araujo et al., 2003; Azeredo et al., 2017; Chang et al., 2005; Chen et al., 2001; Gouli et al., 2004; Grundspenkis & Anohina, 2009; H. Acton et al., 1994; Iqbal et al., 2018) have investigated the problem of evaluation concept maps by comparing the learner's map with a reference map using structural analysis, to recognize possible patterns of solutions, and semantic analysis, for recognition of meanings. In the literature, it is possible to find tools for evaluating concept maps, such as: *COMPASS* (Gouli et al., 2004), *IKAS* (Grundspenkis & Strautmane, 2018; Grundspenkis, 2008a; Grundspenkis & Anohina, 2009), *CMTool* (da Rocha & Favero, 2004; da Rocha et al., 2008). These systems evaluate the correction of propositions in a map by identifying hits and errors. Some of them determine a score in the learner's map, comparing with a map from a specialist. However, in the literature, little has been discussed about the evaluation of maps that take into account different learner's cognitive processes through the analysis of the map construction process. The study of Boss et al. (2019) presents the results of a systematic mapping aiming to identify solutions used for learning assessment through conceptual mapping. The research identified solutions that can be used to assess both structural and semantic aspects and the key categories of Ausubel. However, the research did not find computational solutions that assess learning from the structural and semantic analysis combined with the process of concept maps construction. In addition, we did not find tools that evaluate maps considering the process of map construction with a look on determining meaningful or rote learning signs. The work D. Hay et al. (2008) analyses the structure of the concept map classifying the quality of learning in rote, meaningful learning or non-learning but does not analyse the map construction process. However, no discussion is done about automating the analysis process. It presents a model of teaching practice that emphasizes the importance of analyzing the learner's knowledge construction process with the aim of evaluating the conceptual changes through conceptual mapping. Therefore, the conceptual changes, which occur in the learner's cognitive structure during learning, can be analyzed through the map construction process. As a consequence, this process allows the identification of different conceptual constructions based on the observation of the construction and reconstruction of the map's propositions, as well as indicating conceptual errors made by the learner during the elaboration of knowledge.

Thereby, the analysis of the concept map construction process can: (i) give a better understanding of how the learner constructs and reconstructs knowledge; (ii) allow the observation of changes in learner understanding, rather than simply providing a static assessment of learning at a single point in time (Kinchin, 2000). This analysis is also essential to identify map's propositions related to the processes of *progressive differentiation* and *integrative reconciliation* of Ausubel's theory. All of these aspects are important to identify signs of learning. In this sense, we propose a process model to identify signs of meaningful learning, rote and non-learning from learner's maps and from learner's maps construction process towards an automatization of maps concept evaluation. We developed a case study in order to explore new learning signs from maps construction process which could be added to the process model. The analysis of the case study was done manually by the researchers because our process model has not been automatized yet.

This article focuses on the case study presentation and it is structured into seven sections. Section 2 presents theoretical references about meaningful learning and evaluation of concept maps, raising important questions for the development of this paper, such as conceptual errors in learning evaluation and analysis of concept map construction process. Section 3 describes works related to maps evaluation and meaningful learning, and from the best we know there are no works that combines structural and semantic analysis with map construction process to identify signs of learning. In section 4 we present our process model for evaluating concept maps, that combines structural and semantic analysis with maps construction process through instruments and methodological steps as well the criteria we defined for evaluating maps to identify signs of learning. Section 5 describes the case study which explores learning signs and validate the process model and Section 6 analyzes the main results of the case study. Finally, Section 7 presents the conclusions of the work.

2 Theoretical Reference

In this section, we present concepts about meaningful learning and about maps evaluation that are essential for understanding our proposal. We begin with a brief presentation about meaningful learning from Ausubel's perspective complementing with a vision of this subject from J. D. Novak and Gowin (1984), who have contributions on concretising Ausubel's ideas on concepts maps. We address concept map evaluation in consonance with meaningful learning, considering the importance about taking care of conceptual errors made in map constructions as also the importance of analysing the map construction process.

2.1 Meaningful Learning

According to Ausubel (1968), human beings learn meaningfully via acquisition and retention of concepts and propositions, which are stored in their cognitive structures in a particular, idiosyncratic way. The cognitive content, resulting from the meaningful learning process and constituting its meaning, is the product of the particular way in which the content of the new knowledge is related to the content of the relevant established (anchoring) ideas in the cognitive structure. A meaningful learning process starts with the definition of an anchorage point in the cognitive structure, called by Ausubel a *subsumer*, to which new concepts are connected (Ausubel, 1968; Ausubel et al., 1957). In subsumption, new concepts or ideas in the cognitive structure are assimilated with existing concepts and ideas, refining and reorganizing the meaning of these concepts (J. D. Novak, 2002).

For Ausubel (2000), the storage of informations in the human mind is highly organized, forming a kind of conceptual hierarchy, in which more inclusive concepts are linked to (and assimilated by) more general concepts in the cognitive structure. *Cognitive structure* refers to a *hierarchical structure of concepts* which are representations of the person's experiences (Ausubel, 2000). In this perspective, Ausubel's theory defines cognitive aspects such as subsumption, progressive differentiation and integrative reconciliation, called, in this article, as Ausubel's key categories or simply key categories.

The subsumption process, described by Ausubel in his theory, is called the *assimilation principle*. It is a process that occurs when a given concept *a*, which is potentially meaningful, is assimilated under a more inclusive concept *b* (called subsumer), already existing in the person's cognitive structure, producing a new meaning, resulting from the interaction between them. The occurrence of this process iterated times in the person's cognitive structure results in progressive differentiation. Integrative reconciliation is the association between already existing concepts in the person's cognitive structure. Thus, these concepts are recognized and related in a different way from already existing one, generating new meanings from the reorganization of these concepts (Ausubel, 1962, 2000). A basic premise of the theory of meaningful learning is that during knowledge construction the learner progressively differentiates and, at the same time, integratively reconciles new concepts in interaction with existing subsumers. These processes, according to Ausubel's Theory, are fundamental for human beings to learn meaningly through the acquisition and retention of knowledge (Ausubel, 2000).

Considering meaningful learning of a student about a specific subject, new meanings are assimilated in the cognitive structure to a greater or lesser degree. This depends on how much effort the student makes to seek this integration and on the quantity and quality of his relevant cognitive structure. If the student learns by rote, his cognitive structure is not reconstructed. As there is a relevant difference in the cognitive structure of each learner, there is a continuum in learning (J. D. Novak, 2002). And, according to Ausubel (1968), this continuum can occur from purely rote learning to highly meaningful learning.

Jarvis (1992) and J. D. Novak (1998) define learning as change, since changing in knowledge is a consequence of the integration of new material in the learner's knowledge structure. On the other hand, the absence of change can be interpreted non-learning.

2.2 Concept Map Evaluation

Concept maps are defined as diagrams with hierarchical organization that present relationships between concepts, or between words that represent concepts to form propositions. Concepts are representations of objects, events, situations or properties, designated by a label. A proposition, smallest unit that constitutes knowledge, is a relationship or association between two concepts labeled by a connecting phrase (J. D. Novak & Gowin, 1984). The representation of knowledge, using concept maps, is an alternative to structure and rank concepts of a person's cognitive structure. Concept maps are constructed using a continued application of progressive differentiation (called *ramification* in the map) and integrative reconciliation (called *cross-link* in the map) (da Rocha et al., 2008). The step-by-step observation of the construction of a conceptual map can reveal the evolution of learning about a given domain of knowledge (da Rocha & Favero, 2004).

Concept maps are based on each person's understanding of learning and concept maps created by teachers can differ from those created by learners, each with their idiosyncratic components. This means that there is no single correct map. Similarly, in the map assessment, a learner should not be expected to construct a correct map of a certain content, but rather to present in his conceptual map signs of meaningful learning (Moreira, 2010). Moreira claims that, if learning is meaningful, the learner's cognitive structure is constantly reorganizing itself, and, as a consequence, the same information can be represented in different ways. According to the literature (Grundspenkis, 2009; Ruiz-Primo, 2004), this can present problems when we want to carry out learning assessments through concept maps.

2.2.1 Conceptual Errors in Learning Evaluation

Meaningful learning does not imply the absence of conceptual errors (J. D. Novak, 2002). Novak has dedicated part of his studies (J. D. Novak, 2002; J. D. Novak & Gowin, 1984) to investigate and verify that concept maps are effective tools for revealing the existence of conceptual errors. Ian M. Kinchin and Adams (2010) point out that, when evaluating only the valid propositions, relevant informations about the student construction of meaning can be lost. For example, some invalid propositions constructed by the student may contain valid relations or concepts that can be meaningful in assessing the student's cognitive process of learning, showing the learner's path of understanding. According to the authors, focusing only on valid propositions seems to contradict the constructivist philosophy of using concept maps by failing to recognize the learner's process of meaning construction. From this perspective, conceptual errors are part of the student own process of meaning construction.

2.2.2 Analysis of Concept Map Construction Process for Concept Map Evaluation

Ian M. Kinchin and Adams (2010) argue that the analysis of concepts and relationships in a concept map can not only be used to identify the learner's existing understanding, but it can also be an indication of the student's willingness to progress in his/her learning. According to Canas et al. (2004), it is during the construction of the conceitual map that the creation of meanings occurs, a moment when the learner relates concepts to form propositions. The process of relating concepts to create meaningful propositions in a concept map is the most difficult activity not only because of the large number of possibilities, but also do to the need to establish a relationship between pairs of concepts that are meaningful. Jonassen et al. (1998) highlight the possibility of a non-trivial effort to define a connecting word that represents the relationship between two concepts. According to J. D. Novak (1998), in order to understand how knowledge is constructed, it is essential to understand how the construction process of conceptual structures occurs, thus generating meaning.

The analysis of the construction process allows not only to identify the key categories of Ausubel (progressive differentiation and integrative reconciliation), but also to recognize and store all the conceptual constructions elaborated by the learner, which do not appear in the final static map, as these may have been, for example, modified during their constructions. Therefore, the construction process can give detailed information about the learner's knowledge creation process. In other words, how the learner constructs and reconstructs the propositions in his map. In addition, through the analysis of the construction process, it is possible to identify learner's difficulties in relating concepts in the conceptual mapping.

J. Novak and Canas (2006) argue that there are two important characteristics to facilitate creative thinking: (i) the hierarchical structure represented in a concept map and; (ii) the ability to search and create new cross-links. Figure 1 shows four moments of a concept map construction about the concept *water cycle*. In the four maps the identification of Ausubel's key categories are presented, for example, in Figure 1d integrative reconciliation (cross-link) is represented by dotted lines and progressive differentiation (ramifications) is represented by solid lines. Cross-links demonstrate creative leaps in the construction of new knowledge and, therefore, they should be identified and recognized. We argue this identification is only possible through the analysis of map construction.

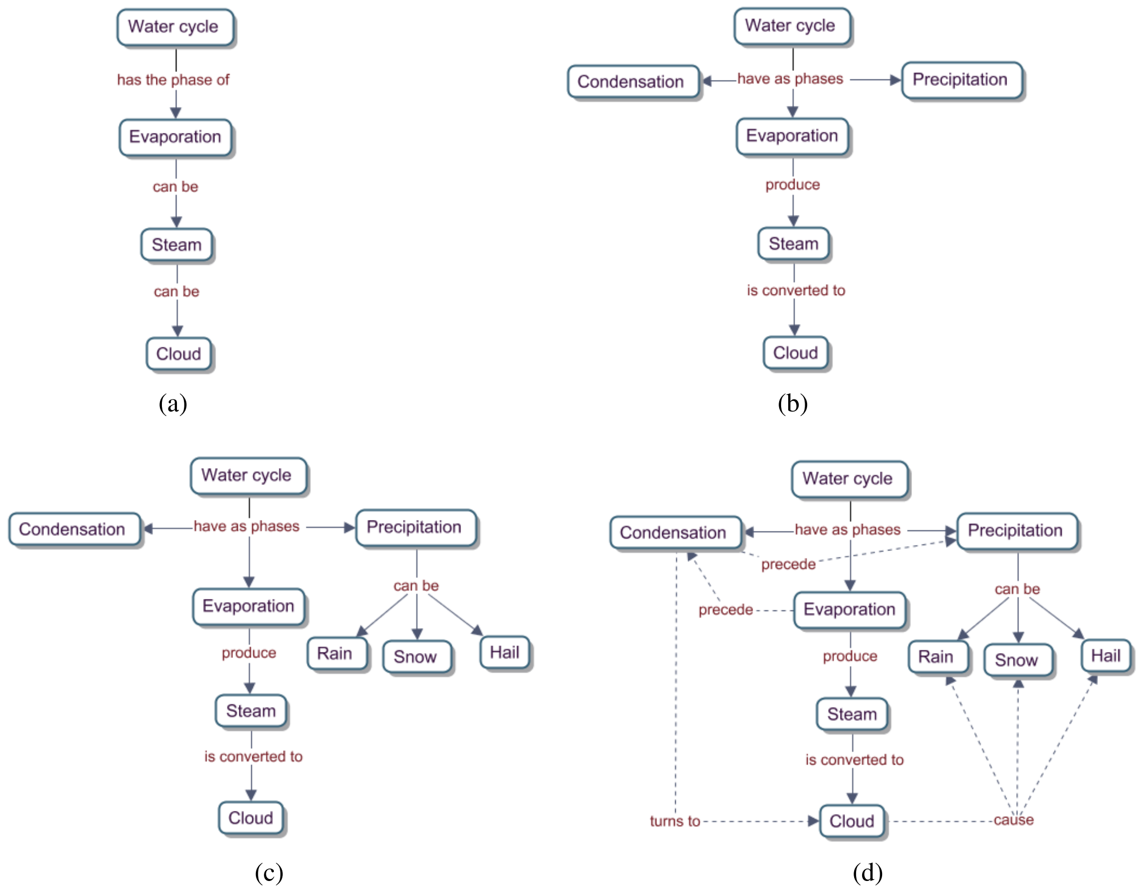


Figure 1: Four moments in the process of constructing a concept map.

Elaborated by the author.

3 Related Work

This section presents some works related to the topic addressed in this article. Several studies have been carried out on the evaluation of concept maps, which are important for the development of new methodologies that can help both the teaching-learning process and assessment itself.

In the context of learning assessment using concept maps, there are several works that deal with this subject in the literature. For example, the works (Anohina & Grundspenkis, 2007;

Anohina et al., 2007; Grundspenkis, 2009) developed an *Intelligent Knowledge Assessment System*, called IKAS, define comparison standards to determine the correctness of each proposition in the learner map against a reference map. The teacher divides a course of study into several stages. At each stage, the teacher includes concepts and relationships in his/her map that were taught to students and uses them to assess knowledge. The assessment is process-oriented and considers the concept maps constructed by learners at each stage of learning, however, at each stage the map construction process is not considered.

The works of da Rocha and Favero (2004) and da Rocha et al. (2004) use different moments in the construction of the conceptual map to assess Ausubel's key categories. These moments can include activities that consider map construction before and after group discussions about a domain specified by the teacher. The developed system, called *CMTool*, captures moments of the construction of the concept map by the learner to help in the assessment of meaningful learning. However, collecting information at different times during the development of the map by the learner is not enough when the objective is, for example, to recognize the key categories of Ausubel. Some cognitive constructions may not be possible to identify at two different moments when capturing the concept map.

Conceptual mapping can be used both to reveal prior knowledge and to measure cognitive changes that occur during learning (D. B. Hay, 2007). According to D. B. Hay (2007), this is a fundamental point when the objective is to carry out evaluation using concept maps. Also according to the author, when a learner maps two instances (i.e., prior knowledge and newly acquired knowledge) of the same topic in the course of his/her study, a comparison of these two or even more instances allows to measure the quality of learning. In this article, like D. B. Hay (2007) we also consider map analysis before and after teaching. However, we believe that the analysis of instances of maps is not sufficient to determine signs of learning and it should be improved with the analysis of all the constructions done by the learner in the course of the maps construction.

The works of D. Hay et al. (2008) and Ian M. Kinchin and Adams (2010) present a qualitative approach to evaluate students' concept maps. Three types of structure patterns are presented in a map: *spoken*, *chain* and *network*. These patterns are used to assess and classify learning by comparing the knowledge structures of students before and after teaching. Learning is classified as rote learning, sequential and isolated learning, meaningful learning, and non-learning: (i) if the learner map is structured as *spoken*, then new concepts can be added through progressive differentiation to the main concept (or initial concept) of the map, but without establishing relationships between already established concepts. This kind of construction represents rote learning; (ii) if the learner map is structured as *chain*, the concepts are related through progressive differentiation in a linear sequence in which each concept is linked only to the one immediately related to it. Thus, the learner may have difficulty in adding new concepts through integrative reconciliation since the content is sequential and isolated; (iii) if the learner map is structured as *network*, then concepts are added by both progressive differentiation and integrative reconciliation forming a strongly connected, hierarchical and integrated network, demonstrating a deep understanding of the topic. This kind of construction represents meaningful learning; non-learning occurs when there are no changes in the learner's conceptual map after teaching. Unlike the works of D. B. Hay (2007) and D. B. Hay et al. (2008) we are not concerned with the structure of the final map, but we are interested in the identification of signs of non-learning, rote learning and meaningful learning from syntactic and semantic analysis as well the map construction process.

The work of Santos et al. (2005) presents a web-based environment for constructing concept maps with a focus on learning monitoring. The environment allows the learners to create maps and change their content by inserting and deleting concepts about a given topic. Furthermore, it is possible to analyze the progress in the construction of the learner's map through a *time-line*, in which all the map construction steps are visualized in animation form, from the beginning to the final map construction. The tool also allows viewing individual versions of the constructed maps. The evaluation of the maps, carried out by the tool, does not consist on comparing the learner's map with a specialist's map, but rather with his/her previous maps so that it is possible to observe how the learner understands a certain concept at different moments in his/her learning trajectory. Although the tool monitors the construction of the map through a timeline, no criteria are defined to characterize learning. Furthermore, the work does not considers the cognitive processes of Ausubel's theory, during the construction of the map, for identifying signs of learning.

Bleckmann and Friege (2023) present in their paper an approach in which students' performance is evaluated using concept maps through machine learning technique. To evaluate the learners' concept maps, a map filling technique is used where the concepts and connections between concepts are made available. Therefore, learners only filled in the connecting words that relate two concepts. For evaluation, the concept map is divided into individual propositions, and a general classification scheme is considered into four categories: one category for wrong answers and three categories for correct answers. In our approach, the learners use the technique of map construction which turns the map evaluation process more complex and we are not limited to categorize answers in correct or incorrect, but we are mainly concerned in the identification of signs of learning. The paper presents results about using different machine learning techniques which is out the scope of our work.

4 A Process Model for Evaluating Concept Maps

Like D. Hay et al. (2008) and D. B. Hay (2007), our approach considers that knowledge, represented in concept maps, should be analyzed before (through prior knowledge) and after (through newly acquired knowledge) teaching. Our process model uses two concept maps to evaluate the changes that occur in the learner's cognitive structure: (i) the first map is used to store the learner's previous knowledge and; (ii) the second map is used to store newly acquired knowledge. The changes identified from the two concept maps are used to classify the type of learning. A *reference map* (constructed by the specialist or teacher) is also used to analyze the correctness of the propositions in the learner's map as found in many works in the literature.

Figure 2 presents a model for identifying signs of learning through conceptual maps that considers the process of map construction, structural and semantic analysis and Ausubel's key categories. Based on this model, we developed a process model for identifying signs of non-learning, rote learning and meaningful learning .

The works of Hay referenced above present criteria to define types of learning to evaluate the conceptual changes that occur in the cognitive structure after new knowledge is acquired. Based on these types of learning, we define signs of learning as rote, meaningful and non-learning from the analysis of isolated propositions in the map. Furthermore, we added the map construction process in our evaluating process model. From the analysis of the map construction process, it is

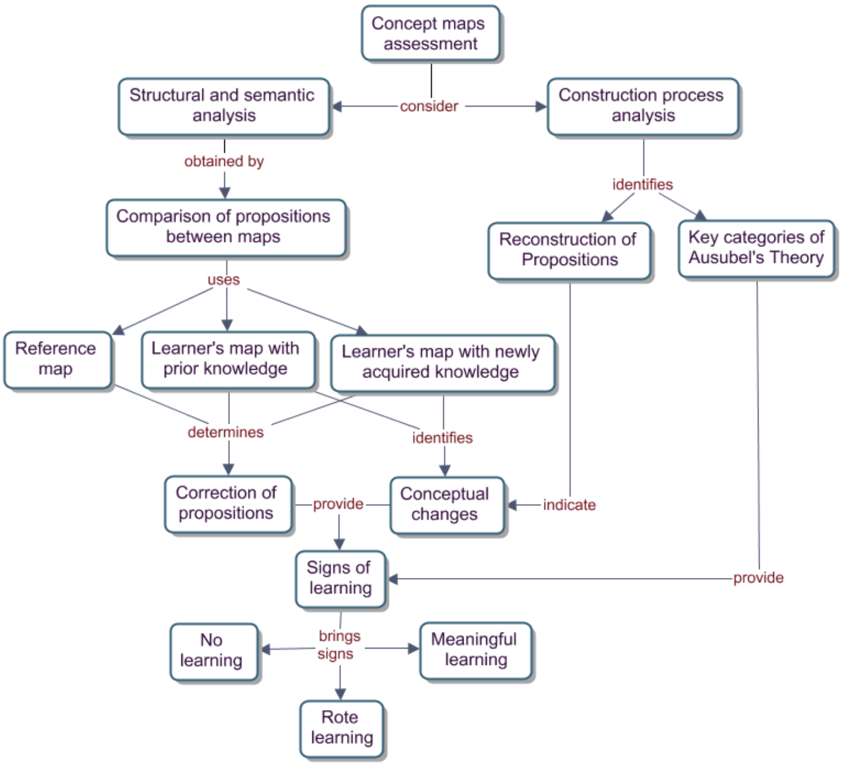


Figure 2: Model for identifying learning signs through concept maps.

Elaborated by the author.

possible to observe all the process of knowledge creation (i.e. propositions) by the learner, as for example, to identify propositions that were inserted and removed during map creation which are not in the learner's final map.

As discussed in Section 2.2.1, conceptual errors must be taken into account because they help to understand how the learner is constructing his knowledge. For example, a learner can be relating a concept that is invalid with a new valid concept that is being acquired. So, we consider from the analysis of the learner's map construction the following type of errors:

- Conceptual errors constructed by the learner in his/her map, but which do not appear in the final map;
- Conceptual errors constructed by the learner in his/her map and that remain until the end of the map elaboration;
- Concepts constructed correctly by the learner but in the final map are presented incorrectly or do not appear.

Additionally, other conceptual errors may exist, which would require a more in-depth analysis of the types of errors that could be identified in the construction of knowledge by the learner, and we let this investigation for future work.

To systematize our process model we follow the method used by D. Hay and Kinchin, 2008 to evaluate concept maps, which comprises the following steps: (i) identification of prior knowledge (considered through the prior knowledge map); (ii) presentation of new content on a specific subject (carried out through the class didactic sequence in the Ausubelian perspective); (iii) evaluation of conceptual changes between prior knowledge and newly acquired knowledge (evaluated through maps of prior and newly acquired knowledge); (iv) measurement of the quality of learning (presented through signs of learning).

Regarding the method used to evaluate concept maps proposed by Hay, we considered the following instruments and methodological steps, represented in Table 1. These instruments and methodological steps are based on Figure 2, however some instruments are abstracted in the figure. For example, the map constructed by the learner is abstracted in the boxes *Construction Process Analysis, Reconstruction of Propositions and Key Categories of Ausuel's Theory.* The error structure was also abstracted from the figure and therefore not represented.

Table 1: Instruments (1-5) and methodological steps (6-10).

Item	Description
1	A decorated learner's prior knowledge map
2	A decorated learner's newly acquired knowledge map
3	A reference map constructed by the specialist or teacher
4	A formal structure of errors (when available)
5	Maps constructed by the instructor from both learner maps (prior knowledge and newly acquired knowledge)*
6	Compare the map with prior knowledge with the reference map (and the error structure) to evaluate the correctness of the map's propositions
7	Compare the map with newly acquired knowledge with the reference map (and the error structure) to evaluate the correctness of the map's propositions
8	Compare the map with prior knowledge with the map with newly acquired knowledge to identify changes that occur in the learner's cognitive structure
9	Compare the conceptual constructions added by the instructor (informations from the map construction process) in the map of *item 5* with the reference map to assess their correctness
10	Identify the key categories of Ausubel

* A map (or a sequence of maps) to store the history of the learner's conceptual constructions is created by the instructor adding and identifying the history of the learner's conceptual constructions.

A concept map is decorated by identifying the propositions as being progressive differentiation or integrative reconciliation, and by identifying the propositions that are not in the final map as being obtained from the construction process.

When we aim to evaluate the learner's concept map, the literature states that it is usual to use a reference map to analyze the correctness of the map's propositions by comparing the propositions in the learner's map with reference map. Therefore, a reference map is taken as a base to start the evaluation process. However, a reference map can not include several propositions semantically correct, that can be constructed by learners. This problem can be solved using formal structures, such as domain ontologies widely used in the literature (Anohina et al., 2006; da Rocha & Favero, 2004; da Rocha et al., 2005; Grundspenkis, 2008b; Iqbal et al., 2018). Ontologies can be used to store not only the propositions of the reference map, but also the propositions constructed by learners, and both the ontologies and the reference map improves the automatization of maps evaluation.

The categories of propositions that can be identified in a concept map comparing the learner's map with a reference map is organized in Table 2:

Table 2: Categories of propositions that can be identified in a concept map.

Categories of propositions	Description
Correct proposition	The proposition constructed in the learner's map is defined as in the reference map. That is, the concepts and the relationship between the concepts are correct.
Non-existent proposition	The proposition constructed in the learner's map does not exist in the reference map neither in the error structure.
Partially correct proposition	The proposition constructed in the learner's map appears in the error structure as: both concepts are correct and the relationship is incorrect; or the relationship between the concepts is correct, but at least one of the concepts is incorrect.
Incorrect proposition	The proposition constructed in the learner's map appears in the error structure as: both the relationship between the concepts and the concepts are incorrect.
Incomplete proposition	The proposition constructed by the learner is incomplete compared with the reference map. That is, the relationship between the concepts or at least one of the concepts was not defined by the learner.

4.1 Criteria for Evaluating Concept Maps

In our evaluation process model learning is interpreted as any change occuring in the individual's cognitive structure and non-learning as the absence of change, following the work of (D. Hay et al., 2008). From this understanding, we consider absence of changes between maps (i.e. absence of insertion or removal of propositions) as non-learning and any changes occurring in concept maps construction are considered as signs of learning.

In Table 3 we organize the changes which can occur in maps construction process with the newly acquired concepts in comparison with the map that represents prior knowledge.

Table 3: Changes identified in concept map contruction process.

Action	Description
Insertion of ramificated proposition	Correct, partially correct or incorrect proposition
Insertion of reconciled proposition	Correct, partially correct or incorrect proposition
Removal of ramificated proposition	Correct, partially correct or incorrect proposition
Removal of reconciled proposition	Correct, partially correct or incorrect proposition
Maintenance of ramificated proposition	Correct, partially correct or incorrect proposition
Maintenance of reconciled proposition	Correct, partially correct or incorrect proposition
Insertion of incomplete proposition	Ramificated or reconciled proposition

In Table 4 we present the criteria we use to evaluate changes in the learner's cognitive structure through concept maps, i.e, changes identified from the first to the second map construction.

We define *Non-Learning* signs from the first to the second map as:

Table 4: Criteria used to evaluate changes in the learner's cognitive structure through concept maps.

Criteria	Description	Proposition Type
Concept Map (Static)		
1	Concepts from previous map are removed	Correct, partially correct or incorrect proposition (ramificated or reconciled)
2	New concepts are added and related to concepts in the map	Correct or partially correct ramificated proposition
3	New relationships are added among existing concepts in the concept map	Correct or partially correct reconciled proposition

NL1: There is an absence of new concepts in the second map;

NL2: There is an absence of new relationships in the second map.

The definition of rote learning from D. B. Hay (2007) and D. B. Hay et al. (2008) considers:

- The second map must contain newly learned concepts which are not presented in the first map;
- The newly learned concepts in the second map are not related to concepts of the first map (prior knowledge) and there are no new relationships among concepts that are persistent from the first to the second map.

Based on the definition of rote learning presented above, we take the following as *Signs of Rote Learning* comparing the first to the second map constructed:

IRL1: Some concepts from the first map are removed, but no new concepts or relationships among concepts are added. Only occurrence of *criterion 1*.

IRL2: New concepts are added, but no concepts from the first map are removed nor new relationships between concepts are added. Only occurrence of *criterion 2*.

IRL3: Concepts from the first to the second map are removed and new concepts are added, but no new relationships among concepts are added. Occurrence of *criteria 1 and 2*.

The items IRL1, IRL2 and IRL3 can be obtained from the analysis of the static conceptual maps.

The identification of meaningful learning requires that more representations be present in the conceptual maps as adressed in D. B. Hay (2007) and D. B. Hay et al. (2008):

- The second map must show the newly learned concepts (which were not included in the first map) and the original (previous) concepts;
- The second map must show that the new knowledge has been related to prior knowledge in a way that it has meaning (e.g., that the relations have valid semantic value);

- The second map must show the existence of new valid relationships in the existing knowledge structure.

Based on the items above about meaningful learning identification, we consider *Signs of Meaningful Learning* as:

IML1 (Figure 3b) A new concept is added by progressive differentiation and related to an already existing concept by integrative reconciliation. There is no addition of new relationships apart from the ones added by integrative reconciliation. Occurrence of *criterion 2* and *criterion 3* (partially).

IML2 (Figure 3c) There is only the addition of new relationships among existing concepts by integrative reconciliation. Only occurrence of *criterion 3* (partially).

IML2r (Figure 3d) A new concept is added by progressive differentiation but is not related to an existing concept by integrative reconciliation. However, there is the addition of new relationships among existing concepts by integrative reconciliation. Occurrence of *criterion 2* and *criterion 3* (partially).

IML3 (Figure 3e) Two new concepts are added by progressive differentiation and related by integrative reconciliation. Occurrence of *criterion 2* and *criterion 3* (partially).

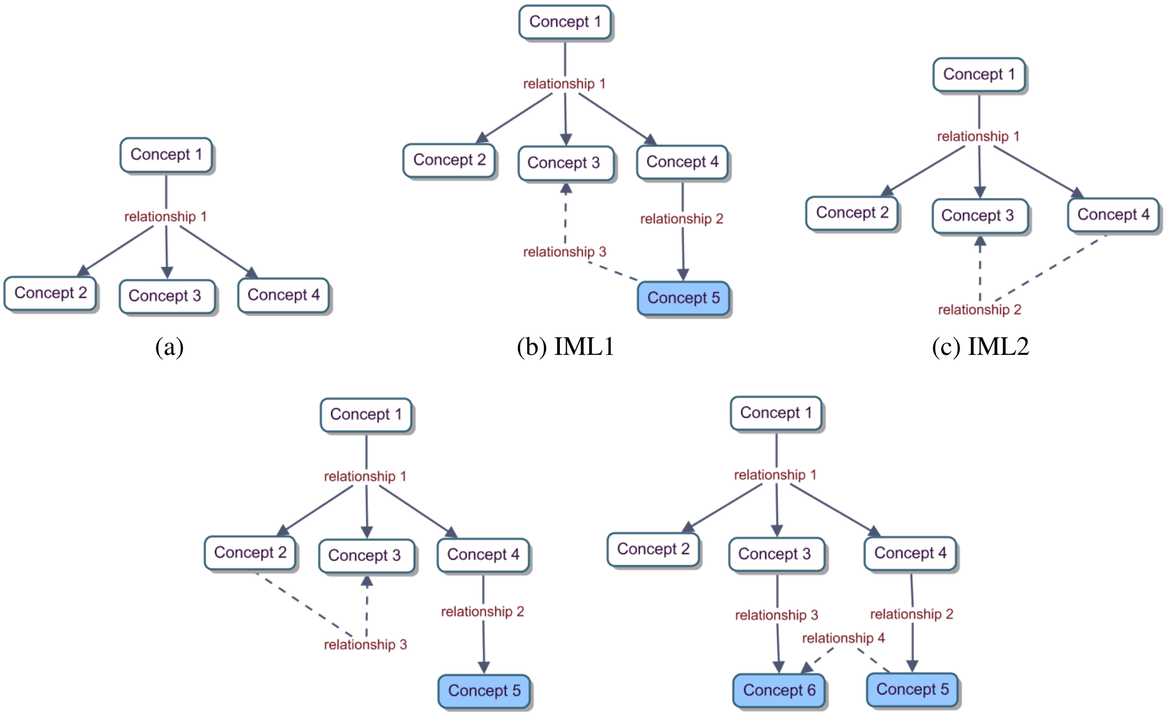
The items IML1, IML2, IML2r and IML3 can be identified from the analysis of the static conceptual maps. Item IML2r is a restricted case of IML2. We can observe that all items are mutually exclusive.

In our work, not all the conceptual constructions presented in the previous knowledge map must be keeped in the newly acquired knowledge map. This is due to the fact that, when constructing the second map, the learner can give up concepts and relationships from the first map that he considers to be wrong or inconsistent with the new concepts acquired. Example 1 illustrates how items IML1, IML2, IML2r and IML3 occur in the concept map.

Example 1 *The map in Figure 3a presents the learner's prior knowledge. The maps in Figures 3b, 3c, 3d and 3e show the newly acquired knowledge corresponding to each case of criteria for signs of meaningful learning which can occur in a concept map.*

5 Case Study

The process model for evaluating concept maps presented in Section 4, mainly rely on concept maps structure, lacking a more detailed analysis of the maps construction process. So, we develop a case study to observe signs of meaningful learning in the process of map contruction.



(a) (b) IML1 (c) IML2

(d) IML2r (e) IML3

Figure 3: Maps of prior and newly acquired knowledge.

Elaborated by the authors.

5.1 Case Study Description: Didactic Sequence in the Ausubelian Perspective

The description of the case study consists of the following items: study objectives, research question, hypothesis and metrics, definition of scenario and context, ethical terms, preparation and instruments for data collection, methodological steps, execution and finally threats to validity.

- **Study Objective:** This case study aims to identify signs of meaningful learning considering the conceptual map construction process and the information contained in maps constructed by learners from a detailed and individual analysis. The objective of the study is detailed in Figure 4, following the *Template Goal-Question-Metric* (GQM) (Basili et al., 1994).
- **Research Question and Hypothesis:** based on the objective defined above, the following Research Questions (RQ) and the null and alternative hypotheses are established:
  - **RQ1:** What new signs of learning can be obtained from the conceptual map construction process?
  - **Null Hypothesis:** There are no new signs of meaningful learning identified during the conceptual map construction process.
  - **Alternative Hypothesis:** There are new signs of meaningful learning identified during the conceptual map construction process.
- **Metrics:** The metrics used to answer the research questions are listed below:

Analyze: the process of constructing concept maps and the constructed maps .

For the purpose to: identify new signs of meaningful learning through the map construction process .

With respect to: the structural organization of the maps and informations obtained from the construction history of the maps.

From the viewpoint of: the researcher as an instructor, during the presentation of the contents, and an observer, during execution.

In the context of: postgraduate students.

Figure 4: Objective of the case study.

Elaborated by the authors.

- **(M1):** All the signs of learning presented in Section 4.1: NL1, NL2, IRL1 to IRL3, IML1 to IML3.
- **(M2):** All the actions of the learner identified during the construction of the concept maps.

- **Scenario Definition:** The case study scenario consisted in using the technique *build a concept map*. According to Ruiz-Primo et al. (2001), this technique can vary in the amount of concepts and linking words that are provided to students by the evaluator. For example, the evaluator can provide the concepts or the relationships, or even ask students to construct a map without providing this information. In our case study, students were free to define the concepts and relationships to construct their concept maps. Students were asked to construct two concept maps. The construction of the first map is intended to represent the learner's prior knowledge, that is, the knowledge she/he already has about the knowledge domain. The second map is intended to represent newly acquired knowledge. Three other maps were used in the analysis and assessment process:

  1. A map containing the history of the learner's conceptual constructions;
  2. An formal structure of errors which contains conceptual errors already made by learners and identified by the teacher in previous evaluations;
  3. A reference map constructed by the specialist.

- **Context Definition:**

  The case study was conducted in an academic environment with postgraduate students from the Postgraduate Program in Scientific Education and Academic Masters Teacher Training at the State University of Southwest Bahia (UESB - Brazil) from the discipline Meaningful Learning by David Ausubel - fundamentals of the processes of teaching and learning of concepts. No restrictions were placed on participating in the case study. All students were invited to participate and the case study was carried out with those who accepted.

The teacher was responsible for teaching classes on the subject of the discipline and the researcher was responsible for teaching about concept maps. Eleven students were selected to participate in the case study, all graduated and many of them working in the teaching field. For the selection of students, knowledge and practice in the use of concept maps were not required.

- **Ethical Terms for Data Collection:** Research which uses procedures that require interactions between the researcher and the participants can result in ethical issues. As this research uses a method of observation with individuals, which is based on the procedures defined by social sciences, the following two ethical terms were elaborated:
  - **Informed Consent Term** (Appendix 1) to the teacher and the students who collaborated with the research, participating in the construction of the conceptual maps and allowing the dissemination of data collected for use in this research;
  - **Authorization Term for the Capture and Use of Video Image** (Appendix 2) for students who collaborated with the research participating in the construction of concept maps, authorizing the capture of video images, using *OBS Studio software*, and the concept maps, for scientific and study purposes.

  The participation of students was free and voluntary and everyone signed the *Informed Consent Term*, and stating the *Authorization Term for the Capture and Use of Video Image*, authorizing the use of the concept maps video images for scientific and study purposes.

- **Instruments for Data Collection:** The following instruments were used:
  - Conceptual map representing the learner's prior knowledge with the history of the learner's conceptual constructions;
  - Conceptual map representing newly acquired knowledge with the history of the learner's conceptual constructions;
  - Conceptual reference map;
  - *OBS Studio software* for screen capture.

- **Methodological Steps:**
  1. Request the signature of the informed consent term and authorization term for the capture and use of video images;
  2. Ask learners to construct a concept map with his/her prior knowledge about: *didactic sequence in the Ausubelian perspective*;
  3. The instructor taught the concepts about the topic adressed and the researcher presented the content about concept maps;
  4. After the presentation of the contents by the instructor, the learners were asked to construct a concept map with the newly learned knowledge.

- **Case Study Execution:** The execution of the case study was based on the instruments and methodological steps defined above and data were collected to be analyzed later. The context for the development of this study was the same for all participants and each participant constructed the concept maps according to the orientations given by the researcher. The researcher participated as an instructor, following the development of the case study. The study was carried out in two stages on the same day and lasted two hours: first it was ministered a class about concept maps and the tools *CmapTools* and *OBS Studio*. After the class, the students were invited to construct a map with their prior knowledge on the topic addressed (didactic sequences in the Ausubelian perspective) and a period of one week was stipulated for the students to construct their map. The second stage took place after the delivery of the first map by the students. The teacher gave a class about the same topic addressed and he asked for the construction of a second map with the newly acquired knowledge. A deadline of one week for the delivery of the map was also stipulated. The participants' data were analyzed manually by the researcher, since there are no tools for this kind of evaluation. After analysis of the maps, four students were selected to stay in the case study. The other students were excluded from the case study due to the following reasons: some videos were with low resolution or were decentralized, not allowing the complete visualization of the construction of the map; some students delivered only one of the maps (map of prior knowledge or newly acquired knowledge); some maps presented bad constructions that were not in accordance with the map contruction restrictions teached in the first class; the maps from one of the students have redundant informations in relation of the others students, not bringing additonal information to the case study.

- **Threats to Validity:** The main threats of this case study are: (i) participants' lack of familiarity in using concept maps which can make it difficult to externalize their knowledge using concept maps; (ii) little familiarity with *CmapTools* and *OBS Studio* tools, which can lead to difficulties in the construction of maps using these tools, as well as difficulties in recording the screen or even recording in low quality making it impossible to analyse the videos generated.

5.2 Reference Map

Figure 5 shows the reference map constructed by the instructor about the content *didactic sequences in the Ausubelian perspective*. This map, like all the concept maps presented in this case study, identifies Ausubel's key categories using solid lines for progressive differentiation and dotted lines for integrative reconciliation. In order to facilitate the visualization of propositions in the concept maps, some concepts are duplicated in the figure, as for example the concepts *class plan*, *teaching method*, *content*, *assessment of learning*, *learning assessment of the pedagogical process*, among others.

6 Case Study Results

The collected data are of three learners, each one constructing two concept maps, one before and one after the application of the class *didactic sequences in the Ausubelian perspective* by the

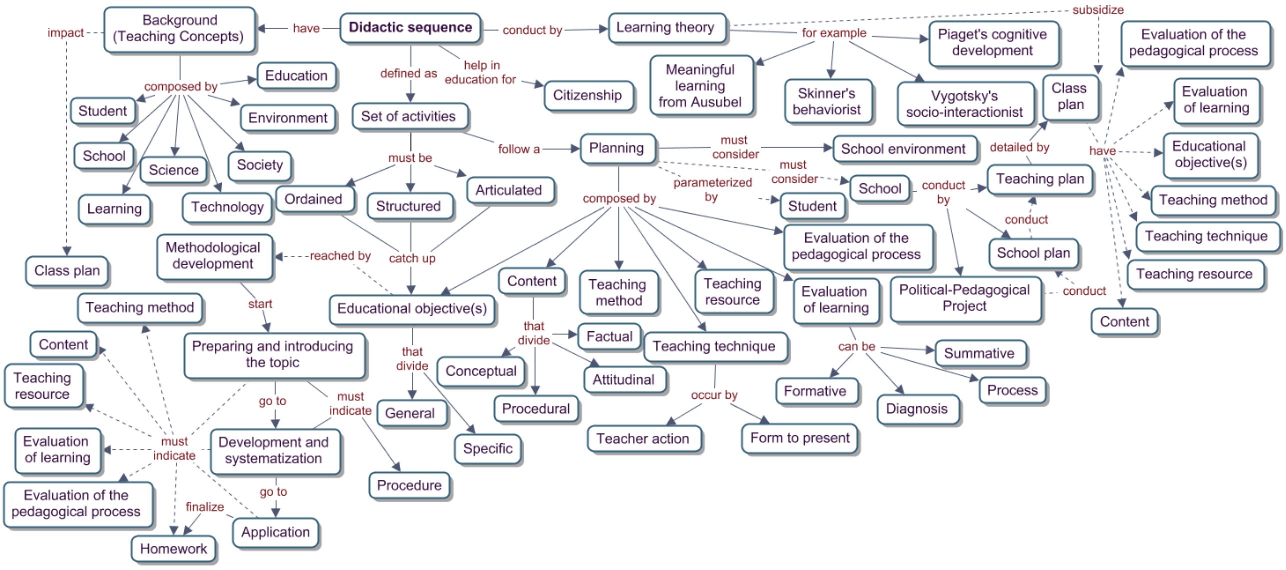


Figure 5: Reference map on didactic sequences in the Ausubelian perspective.

Elaborated by the teacher.

teacher. The maps in Figs. 6, 7, 8, 9, 10 and 11 were elaborated by the researcher observing the process of construction of the propositions through the video made available by the learners.

6.1 Learner 1

Figure 6 shows the concept map with the learner's previous knowledge and Figure 7 shows the concept map with the newly acquired knowledge.

Figure 6: Concept map of learner 1 with prior knowledge.

Elaborated by Learner 1.

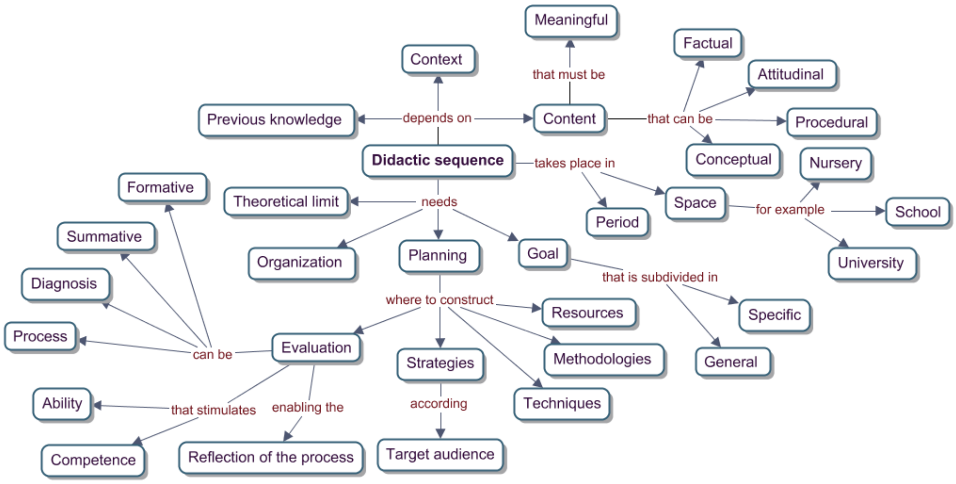


Figure 7: Concept map of learner 1 with newly acquired knowledge.

Elaborated by Learner 1.

6.1.1 Data Collection

We present the collected data in the following tables:

- **Table 5** presents the comparison between the *reference map* (Figure 5) and *prior knowledge map* (Figure 6);
- **Table 6** presents the comparison between the *reference map* (Figure 5) and *newly acquired knowledge map* (Figure 7);
- **Table 7** presents the comparison between the *prior knowledge map* (Figure 6) and *newly acquired knowledge map* (Figure 7).

The propositions in *purple* in Tables 5 and 6 are classified as *non-existent*, since they do not appear in the reference map. Thus, these propositions were manually analyzed by the teacher and classified as correct, partially correct or incorrect. For reasons of space, propositions that have the same connecting word were placed in a single line and the alternative concepts are enclosed in braces. For example, the propositions: *Didactic sequence takes place in Time* and *Didactic sequence takes place in Space* are represented together in the tables as: Didactic sequence *takes place in* {Time | Space}.

Table 5: Comparison between the reference map and the prior knowledge map.

Categories of propositions	Proposition in the student's map
Correct ramificated proposition	- Didactic sequence *depends on* {Previous knowledge | Context | Content}; - Content *that can be* {Conceptual | Procedural | Attitudinal}; - Didactic sequence *takes place in* {Time | Space}; - Space *for example* {Nursery | School | University}; - Didactic sequence *needs* {Theoretical limit | Organization | Planning | Goal};

continues on the next page

Table 5: Comparison between the reference map and the prior knowledge map. (continuation)

Categories of propositions	Proposition in the student's map
	- Goal *that allows* {Criticality | Autonomy}; - Planning *where to construct* {Methodologies | Strategies | Evaluation}; - Strategies *according* Target audience;
Partially correct and incorrect ramificated proposition	- Content *that must be* Meaningful; - Evaluation *that stimulates* {Ability | Competence};

Table 6: Comparison between the reference map and the newly acquired knowledge map.

Categories of propositions	Proposition in the student's map
Correct ramificated proposition	- Didactic sequence *depends on* {Previous knowledge | Context | Content}; - Content *that can be* {Conceptual | Procedural | Attitudinal | Factual}; - Didactic sequence *takes place in* {Time | Space}; - Space *for example* {Nursery | School | University}; - Didactic sequence *needs* {Theoretical limit | Organization | Planning | Goal}; - Planning *where to construct* {Methodologies | Strategies | Evaluation}; - Strategies *according* Target audience; - Goal *that is subdivided in* {Specific | General}; - Planning *where to construct* {Resources | Techniques}; - Evaluation *enabling the* Reflection of the process; - Evaluation *can be* {Formative | Summative | Diagnosis | Procedural};
Partially correct and incorrect ramificated proposition	- Content *that must be* Meaningful; - Evaluation *that stimulates* {Ability | Competence};

Table 7: Comparison between the prior knowledge map and the newly acquired knowledge map.

Description	Proposition in the student's map
Insertion of ramificated correct proposition in the map of Figure 7	- Content *that can be* Factual; - Goal *that is subdivided in* {Specific | General}; - Evaluation *enabling the* Reflection of the process; - Evaluation *can be* {Formative | Summative | Diagnosis | Procedural}; - Planning *where to construct* {Resources | Techniques};
Removal of ramificated correct proposition in the map of Figure 6	- Goal *that allows* Criticality; - Goal *that allows* Autonomy;
Correct ramificated proposition maintained in the map of Figure 7	- Didactic sequence *depends on* {Previous knowledge | Context | Content}; - Content *that can be* {Conceptual | Procedural | Attitudinal}; - Didactic sequence *takes place in* {Time | Space}; - Space *for example* {Nursery | School | University}; - Didactic sequence *needs* {Theoretical limit | Organization | Planning | Goal}; - Planning *where to construct* {Methodologies | Strategies | Evaluation}; - Strategies *according* Target audience;
Partially correct and incorrect ramificated proposition maintained in the map of Figure 7	- Content *that must be* Meaningful; - Evaluation *that stimulates* Ability; - Evaluation *that stimulates* Competence;

By briefly analyzing Table 5, we can interpret that the proposition *Content that can be Conceptual* in the learner's map was classified as correct, as it is on the reference map. The propositions which are colored purple, were not constructed by the expert in the reference map and, therefore, were analyzed manually. The same interpretation can be made in the Table 6. In the

Table 7 we identify the changes that occur between the previous and newly acquired knowledge map. For example, the proposition *Content that can be Factual* was not in the map of prior knowledge, but it was included in the map of newly acquired knowledge.

In order to identify whether there are signs of rote or meaningful learning we use the process model developed in Section 4.1, and the data in Table 7.

- **Signs of Rote Learning:** There are signs of rote learning since the propositions satisfy **IRL3**: two correct ramificated propositions were removed, as for example: *goal that allows criticality* and ten correct ramificated propositions were inserted, as for example: *content that can be factual*, but no new relationships between concepts were added.
- **Signs of Meaningful Learning:** There are no signs of meaningful learning, as the propositions do not satisfy **IML**, that is, there are no ramificated propositions.

6.2 Learner 2

Figure 8 shows the concept map with the learner's previous knowledge and Figure 9 shows the concept map with the newly acquired knowledge.

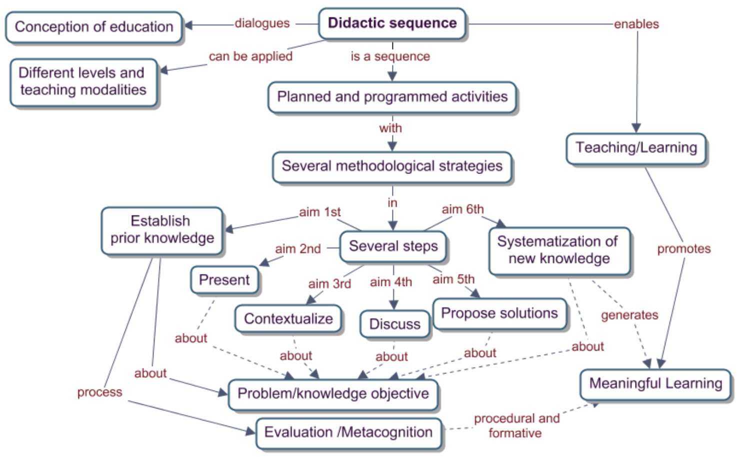


Figure 8: Concept map of learner 2 with prior knowledge.

Elaborated by Learner 2.

The tables from learner 2 and learner 3 are constructed and analyzed similarly as from learner 1 and therefore are not presented in this paper.

From the analysis of prior knowledge map compared to the newly acquired knowledge map, it was possible to identify signs of rote and meaningful learning.

- **Signs of Rote Learning:** There are signs of rote learning because the propositions satisfy **IRL3**: eleven correct ramificated propositions, as for example: *didactic sequence dialogues conception of education* and one correct reconciled proposition (*avaluation/metacognition*

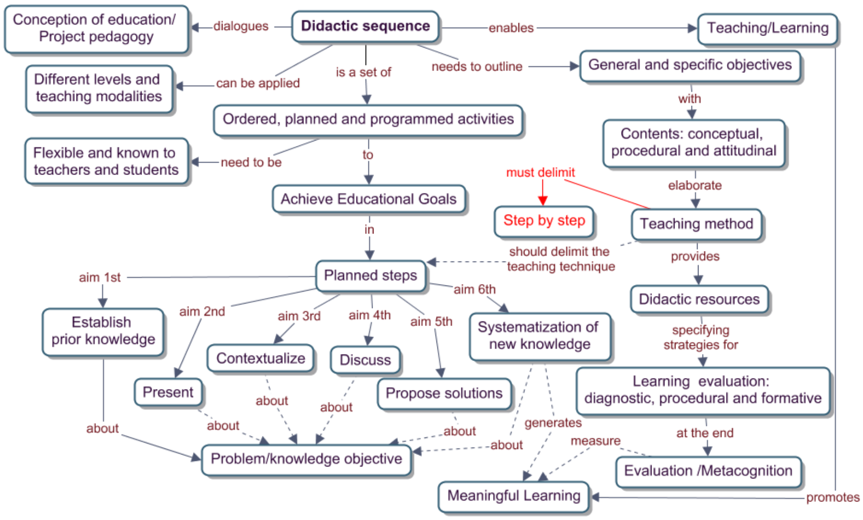


Figure 9: Concept map of learner 2 with newly acquired knowledge.

Elaborated by Learner 2.

procedural and formative meaningful learning) were removed. Thirteen correct ramificated propositions, as for example: *didactic sequence is a set of ordered, planned and programmed activities* and one partially correct ramificated proposition (*teaching method provides didactic resources*) were inserted; and satisfy **IRL4**: one partially correct ramificated proposition (*teaching method must delimit step by step*) was inserted/removed (construction process).

- **Signs of Meaningful Learning:** There are signs of meaningful learning because the propositions satisfy **IML2:** one partially correct reconciled proposition (*evaluation/metacognition measure meaningful learning*) was inserted.

6.3 Learner 3

Figure 10 shows the concept map with the learner's previous knowledge and Figue 11 shows the concept map with the newly acquired knowledge.

Considering the analysis of prior knowledge map compared to the newly acquired knowledge map, it is possible to see whether there are signs of rote and meaningful learning.

- **Signs of Rote Learning:** There are signs of rote learning as the propositions satisfy **IRL3**: ten correct ramificated propositions, as for example: *evaluation/metacognition measure meaningful learning*, four correct reconciled propositions, as for example: *didactic planning evaluate teaching practice* and five partially correct ramificated propositions, as for example: *potentially meaningful materials evaluate individual/collective relationships* were removed. Thirteen correct ramificated propositions, as for example: *individual and collective learning readjust didactic sequence* and three partially correct ramificated propositions, as for example: *steps re-evaluate evidence of individual and collective learning* were inserted; and satisfy **IRL4**: six correct ramificated propositions, as for example: *evidence*

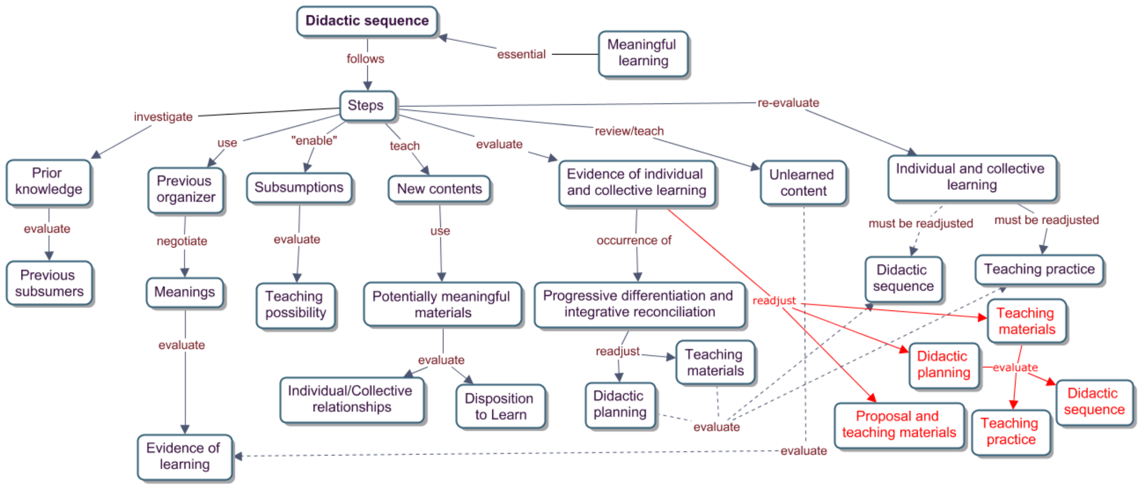


Figure 10: Concept map of learner 3 with prior knowledge.

Elaborated by Learner 3.

of individual and collective learning readjust teaching materials and four partially correct ramificated propositions, as for example: *teaching materials evaluate Didactic sequence* were inserted/removed (construction process).

- **Signs of Meaningful Learning:** There are signs of meaningful learning because the propositions satisfy **IML1:** Two correct reconciled propositions, as for example: *potentially meaningful material define instruments progressive evaluation* were inserted; satisfy **IML2:** four correct reconciled propositions, as for example: *subsumptions use potentially meaningful material* were inserted; and satisfy **IML3:** five partially correct reconciled propositions, as for example: *prior knowledge use potentially meaningful material* were inserted and two correct reconciled propositions, as for example: *integrative reconciliation re-elaborate planning* were inserted.

6.4 Considerations about the Case Study

The research question defined in this case study is answered by analyzing: (i) the categories of propositions defined in Table 3 - *Changes identified in concept map contruction process*; (ii) correction of the propositions defined in Table 4 - *Criteria used to evaluate changes in the learner's cognitive structure through concept maps*; (iii) the cognitive processes of progressive differentiation and integrative reconciliation, as defined in Ausubel's theory, represented in the concept map from the types of propositions (ramification and cross-link); (iv) the metrics M1 and M2, which contemplate learning signs and the learner's actions during the elaboration of the map.

The criteria in Table 4 were combined with the changes in Table 3, i.e, with the propositions of the map construction process, to assess changes in the learner's cognitive structure, which enabled to identify new criteria for the learning evaluation using concept maps. So, Table 4 should be extended with two new criteria, shown in Table 8.

From these new criteria we added two new signs, defined below:

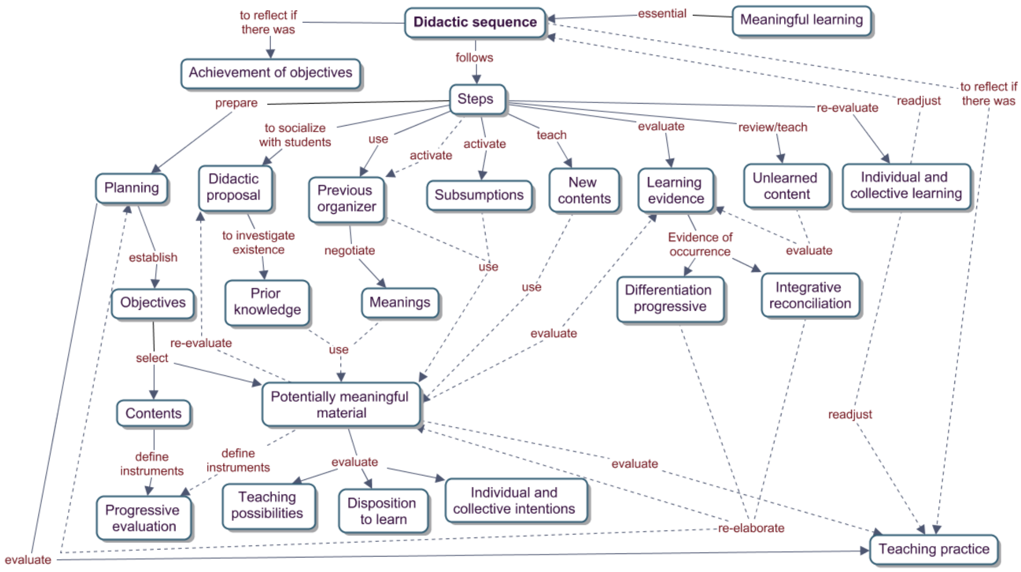


Figure 11: Concept map of learner 3 with newly acquired knowledge.

Elaborated by Learner 3.

Table 8: New criteria to assess changes in the learner's cognitive structure.

Criteria	Description	Proposition Type
	Concept Map (Construction Process)	
4	Added and related concepts in the concept map are removed	Correct or partially correct ramificated proposition
5	New relationships added between concepts in the concept map are removed	Correct or partially correct reconciled proposition

IRL4: Addition followed by removal of a proposition by progressive differentiation identified through the construction process. Occurrence of *Criterion 4*.

IML4: Addition followed by removal of a proposition by integrative reconciliation identified through the construction process. Occurrence of *Criterion 5*.

We argue that the signs *IRL4* and *IML4* are relevant because during the elaboration of the concept map, the learner is constructing his knowledge and propositions or relationships inserted and removed, which do not appear in the final static map, can be useful for the teacher to understand the learning cognitive process.

Our method provides data from all propositions constructed by the learner, evaluating whether they are correct, incorrect or partially correct, either through the static maps or by observing the construction process. These data can be used by the teacher to carry out a qualitative assessment of meaningful learning. For example, it was observed in the case study that in the map construction process, the learner 1 inserted and removed two correct ramificated propositions in the prior knowledge map:

<Goal that allows Criticality>

<Goal that allows Autonomy>

This information shows that the learner had doubts regarding the correctness of these propositions, but in some measure, it can be considered a sign of meaningful learning construction. It was also observed that the learner constructed correct propositions not predicted by the teacher in his reference map, but which may be in the domain ontology. For example:

<Planning where to construct Resources>
<Planning where to construct Techniques>
<Evaluation can be Formative>
<Evaluation can be Summative>
<Evaluation can be Diagnosis>
<Evaluation can be Procedural>

These informations provided by the learners can help the teacher to better understand how the learner constructs and reconstructs knowledge, enabling the teacher to improve his teaching-learning practices, aimed a more individualized teaching. It can also help the teacher to enrich his reference map with new information constructed by the learners. Therefore, providing signs of learning obtained through the map construction process can help in the assessment task, since the process provides informations about the cognitive processes of progressive differentiation and integrative reconciliation, as well as aspects of the construction of the learner's knowledge such as errors he makes during this process.

In addition to the case study presented in this paper, another case study was carried out with five other learners, using the same process model defined in the Sections 4, to investigate the existence of other criteria and even new signs of learning. However, no new criteria and signs other than those presented in this paper were identified.

6.5 Limitations of the Case Study

One of the limitations of the case study was its application with few apprentices, due to the data analysis being carried out manually. Another limitation was the specific context to which the case study was applied, i.e. *didactic sequences in the Ausubelian perspective*. So, the development of other case studies to look for new signs of learning is recommended to add more confidence to the process model presented here.

7 Conclusions and Future Work

This paper presented a proposal for evaluating concept maps by incorporating the map construction process analysis besides syntactic and semantic analysis. Our proposal consists in a map evaluation process model which encompasses several systematic criteria for the identification of meaningful learning signs, rote learning signs and non-learning signs according to Ausubel theory.

We showed the results of a case study which demonstrated that the citeria used from syntactic and semantic analysis have been sufficient regarding the learning signs identified, evidencing that such criteria were well defined. Regarding the map construction process, new signs were identified which made other criteria be incorporated into the map evaluation process model. We can not assert the completeness of the criteria due to conceptual maps represent cognitive constructions which are idiosyncratic processes and it is difficult to predict all possible construnctions types. However, we argue that the criteria cover a large number of cases and are therefore effective in finding signs of learning.

In the case study, the maps were evaluated manually and many tables were also constructed manually by the analysis of each proposition, a difficult and exhausting task which becomes unfeasible in teaching practice when a large number of learners are evaluated. We are interested in formalizing the map evaluation process model in order to generate a computational tool to automate the evaluation process. We are also considering developing a scoring system by which signs of learning can be evaluated quantitatively.

Acknowledgements

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Appendix 1

INFORMED CONSENT TERM

Dear:

You are being invited to participate, as a volunteer, in a survey carried out as data collection for the development of the research called *a process model to looking for signs of learning using concept maps: a case study*. To carry out this part of the research, you will be asked to build, step-by-step, a conceptual map on a domain of knowledge that is characterized as data collection for the research in question. We guarantee here that this procedure will not pose any risk to the physical or moral integrity of the participants, as well as direct expenses, losses or benefits.

Participating in this research may expose participants to minimal risks such as embarrassment and/or embarrassment (for example, when remembering highly stressful situations) when answering a question; embarrassment of interacting with strangers; taking time to participate in the study; fear of eventual repercussions and stigmatization. If this occurs, participants will be instructed to stop participating in the study, if desired, and return later.

Your participation is voluntary and confidential, and the data collected is exclusive for use in this survey. We emphasize that the withdrawal of consent is allowed at any time without punishment to the participant or modification in the way in which the researcher is assisted, who will treat his/her identity with professional standards of secrecy. After being clarified (a) about the following information, if you accept to be part of the study, sign at the end of the document, which is in duplicate. Thanks for your collaboration!

INFORMED CONSENT TERM

I agree to participate, as a volunteer, in the research project entitled "*a process model to looking* *for signs of learning using concept maps: a case study*” which has as responsible researchers Silvio Luiz Bragatto Boss, Aline Maria Santos Andrade and Ecivaldo de Souza Matos.

The participation will consist of the step-by-step construction of a conceptual map using the CmapTools tool on a knowledge domain to be specified. The entire process of constructing the concept map must be recorded using the OBS Studio tool and made available to the researcher.

I understand that this study has a research purpose, that the data obtained will be disclosed following the ethical guidelines of the research, with the preservation of the anonymity of the participants, thus ensuring my privacy. I know that I can withdraw from my participation in the survey at any time and that I will not receive any payment for this participation.

I, ____, was informed of the objectives of the research "a process model to looking for signs of learning from concept maps: a case study" in a clear and detailed way and clarified my doubts. I know that at any time I will be able to request new information and change my decision to participate if I wish. I declare that I agree to participate. I received a copy of this informed consent term and was given the opportunity to read and clarify my concerns.

City, ________,_________________________,_______

____

Research participant signature

Appendix 2

AUTHORIZATION TERM FOR CAPTURE AND USE OF VIDEO IMAGE

I, ____, after knowing and understanding the objectives, methodological procedures, risks and benefits of the research, as well as being aware of the need for the capture and use of video image by means of software for the construction of the conceptual map, specified in the Informed Consent Term, I AUTHORIZE, through this term, the researchers Silvio Luiz Bragatto Boss, Aline Maria Santos Andrade and Ecivaldo de Souza Matos of the research project entitled "*a process model to looking for signs of learning using concept maps: a case study*" to use the collected data without any financial burden to any of the parties, keeping my name or any information that identifies me confidencial. At the same time, I release the use of the conceptual map images for scientific and study purposes (books, articles and slides), in favor of researchers and research, as specified above, in compliance with the provisions of Article 81 of the Civil Code and Law N. 9,610/98 (which govern and protect individual rights regarding the right to image and copyright of audiovisual productions, respectively).

City, ________,_________________________,_______

____

Research participant signature