CMTool: Facilitating Meaningful Learning Practice in the Classroom

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CMTool: Facilitando a Aprendizagem Significativa em Sala de Aula

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Abstract. In the area of school education, many researchers support the idea that the educational process can be greatly enhanced with the use of technologies resulting from advances in Computer Science. These technologies allow for the construction of computational environments that aim at facilitating teaching, learning, and learning assessment. In this article we present one of these environments: CMTool. Its supporting educational concept is meaningful learning and the computational tools used to implement it are domain ontologies and a genetic algorithm (GA); its main focus is learning assessment via concept maps (CMs). In CMTool, domain ontologies – drawn by teachers for discipline topics – are searched by a GA, which builds populations of CMs. These populations are semantically comparable to the CMs students submit for assessment. The resulting assessment respects students' learning style and linguistic choices, taking into account idiosyncratic forms of learning.

Keywords: Domain Ontologies. Genetic Algorithms. Meaningful Learning. Concept Maps. Learning Assessment.

Resumo. Na área da educação escolar, muitos pesquisadores compartilham a idéia segundo a qual o processo educacional pode ser substancialmente melhorado com o uso de tecnologias resultantes dos avanços na Ciência da Computação. Estas tecnologias permitem construir ambientes computacionais destinados a facilitar o ensino, a aprendizagem e a avaliação da aprendizagem. Neste artigo apresentamos um destes ambientes: CMTool. Sua base educacional teórica é a aprendizagem significativa e as principais ferramentas computacionais usadas para implementá-lo são ontologias de domínio e um algoritmo genético (AG); seu foco principal é avaliação da aprendizagem mediada por mapas conceituais (MCs). No CMTool, ontologias de domínio – desenhadas por professores para os tópicos das disciplinas – são pesquisadas por um AG, o qual constrói populações de MCs. Estas populações são semanticamente comparadas aos MCs que os estudantes submetem para avaliar suas aprendizagens. A avaliação, feita desta forma, leva em conta o caráter idiossincrático da aprendizagem de cada estudante.

Palavras-chave: Ontologia de Domínio. Algoritmo Genético. Aprendizagem Significativa. Mapas Conceituais. Avaliação da Aprendizagem.

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1 Introduction

Technological advances in Computer Science have leveraged progress and research in almost all other fields of human activity. Artificial Intelligence techniques, for example, provide ways of solving problems in disciplines ranging from economy to ecology (HOLLAND, 1999). In the area of school education, many researchers support the idea that the educational process can be greatly enhanced with the use of technologies resulting from advances in Computer Science (JONASSEN, 1996). These technologies allow for the construction of computational environments that aim at facilitating teaching, learning, and sometimes learning assessment.

With the dissemination of distance learning, learning assessment has become a constant concern. In large-scale virtual learning environments, teachers have to cope with the assessment of virtual groups of, for example, hundreds of students. A teacher who assigns such a group the task of preparing a summary of an article will have to deal with the overload deriving from the assessment of hundreds of essays. Consequently, an alternative, more easily assessable way of expressing students' beliefs is highly desirable.

Concerning the construction of educational environments, two fundamental problems arise: the choice of a learning theory to serve as the basis for the environment and, even more important, the identification of implementable aspects of this theory (GIRAFFA, 1999). According to MOREIRA (1999), all learning theories are based on one or more of the following philosophies: Behaviorism, Cognitivism, and Humanism. These philosophies try to explain the learning process from particular perspectives. Among them, Cognitivism has played a major role in Educational Psychology in the last decades.

An important cognitivist author is David Paul Ausubel, who developed the *Assimilation Theory* (AUSUBEL,1968; 2000). According to Ausubel, human beings learn meaningfully via acquisition and retention of concepts and propositions, which are stored in their cognitive structures in a particular, idiosyncratic way. This particular way of storing concepts and propositions is what forms the meanings human beings assign to experiences. A new meaningful learning process starts with the definition of an anchorage point in the cognitive structure, called *subsumer*, to which new concepts are connected. As a result, new learning essentially depends on the quantity and quality of the subsumers, as well as their stability and differentiability in the apprentice's cognitive structure (AUSUBEL, 1968). Applying adequate mental processes, called *progressive differentiation* and *integrative reconciliation*, human beings *construct* the knowledge stored in their cognitive structures.

Although apparently simple, Ausubel's ideas are not easily put into classroom practice without proper understanding of the processes through which people learn meaningfully, i.e., there is a fundamental necessity of learning the concepts of progressive differentiation and integrative reconciliation before applying them to usual school topics. Aware of this difficulty, Joseph Donald Novak developed, during the sixties, a pedagogical tool called *cognitive map* or *concept map* (CM) (NOVAK, 1998; NOVAK & GOWIN, 1984). According to Novak, a CM represents part of a person's cognitive structure, revealing his or her particular understanding of a specific knowledge area. It contains concepts and propositions in graphical form, and it is constructed by the continued application of progressive differentiation and integrative reconciliation. This way, a sequence of CMs constructed by a person can illustrate the evolution of this person's understanding of the topic (ROCHA & FAVERO, 2004). CMs are, consequently, a viable, computable, and theoretically-sound alternative to the problem of expressing and assessing students' learning. They can be used, among many other things, as alternatives to usual essays, decreasing the amount of work demanded from the teacher during assessment. Nevertheless, the assessment of hundreds of CMs is still a considerable source of effort. Educational environments based on CMs focus on automating parts of this process.

In this article, we present CMTool (www.inf.ufpa.br/pesquisa/Publico /CMTool), an educational environment based on the Assimilation Theory and on Concept Maps. The implementation of the environment applies a combination of Artificial Intelligence techniques (ROCHA, DA COSTA Jr. & FAVERO, 2004), like ontologies and genetic algorithms, as well as information visualization techniques, whose objective is to improve perception and usability of the environment. It was designed to facilitate CM-based teaching, learning and, most of all, assessment. There are other environments based on CMs in the literature. Most of them are only CM editors, as in CAÑAS, HILL et al. (2004). Some, however, focus on CM assessment (e.g. ARAÚJO, MENEZES & CURY (2003)). The general tendency of these environments is to compare the CM developed by the student to a reference CM constructed by the teacher or by a specialist. This approach does not find support in cognitivist principles, because it forces the comparison between potentially different – and potentially correct – understandings of the same reality. The result of this comparison can be used to assign a degree to a student, but it can hardly be considered learning assessment, from a cognitivist perspective.

Differently from this approach, CMTool supports learning assessment implementing two complementary mechanisms: (i) it provides teachers with the opportunity of constructing domain ontologies in which they can list the concepts considered essential to cover the learning of a topic of a discipline, as well as their interrelationships; (ii) it encompasses a genetic algorithm (GA) capable of emulating the cognitive processes described in the Assimilation Theory, and capable of generating various CMs based on the teacher's ontology, with the help of an inference engine.

A fundamental requirement that guided the construction of CMTool was that the CMs generated by the GA should be comparable to the students' maps presented for assessment. This modus operandi supports the idea of individual, idiosyncratic learning, in accordance with Ausubel's learning theory and the cognitivist philosophy. In CMTool, part of the teachers' work is to build domain ontologies for the topics of their disciplines, with the help of an ontology editor. Students express their conceptual learning, mapping the concepts teachers used in the ontology. In order to do this, students use the CM editor available in the environment. Eventually, students submit their CMs for automatic assessment. Detailed explanations on the roles of teachers and students in the environment, as well as how it accomplishes assessment in an idiosyncratically, cognitivist-aware manner, are provided in the next sections of this article.

This article contains nine sections. Section 2 details the relationship between Ausubel's Assimilation Theory and Novak's Concept Maps. Section 3 presents the CMTool environment, as well as its modules, together with a brief description of each. Section 4 details a use scenario of the environment, from the teachers' perspective, and Section 5 describes how students use the environment individually or cooperatively. Section 6 describes the inner functioning of the environment during assessment: the generation, by the GA, of populations of CMs comparable to the student's CM, and the results generated by the assessor component. Finally, Section 7 lists future research and Section 8 presents our final considerations.

2 The Assimilation Theory and Concept Maps

The Assimilation Theory (AUSUBEL, 1968; 2000) was developed by David Paul Ausubel in the 1960s and tries to explain learning as the acquisition of new concepts, and the immersion of these concepts in the individual's *cognitive structure* – a mental structure in which knowledge organization and integration are processed. The main concept of this theory is *meaningful learning*: a process in which new information is linked to some specific relevant aspect of the individual's cognitive structure, which Ausubel defined as the *subsumer concept* (or only *subsumer*). Other basic principles described in the Assimilation Theory are *progressive differentiation* and *integrative reconciliation*, which are cognitive processes that explain the subsumption of new concepts in the cognitive structure.

Joseph Novak, based on Ausubel's ideas, developed a methodological tool called Concept Map (NOVAK, 1998; NOVAK & GOWIN, 1984). A CM represents an abstraction of an individual's cognitive structure, and the changes that occurred inside it. It contains a graphical representation of *concepts* and *propositions*. A concept is a regularity perceived in objects, events, situations, or properties designed by a label, and a proposition is a relationship or association between two or more concepts labeled by a linking phrase. A proposition forms a statement about an event, object or idea. Figure 1 shows a CM about human learning. One of its propositions is <HUMAN LEARNING can be COGNITIVE LEARNING>.

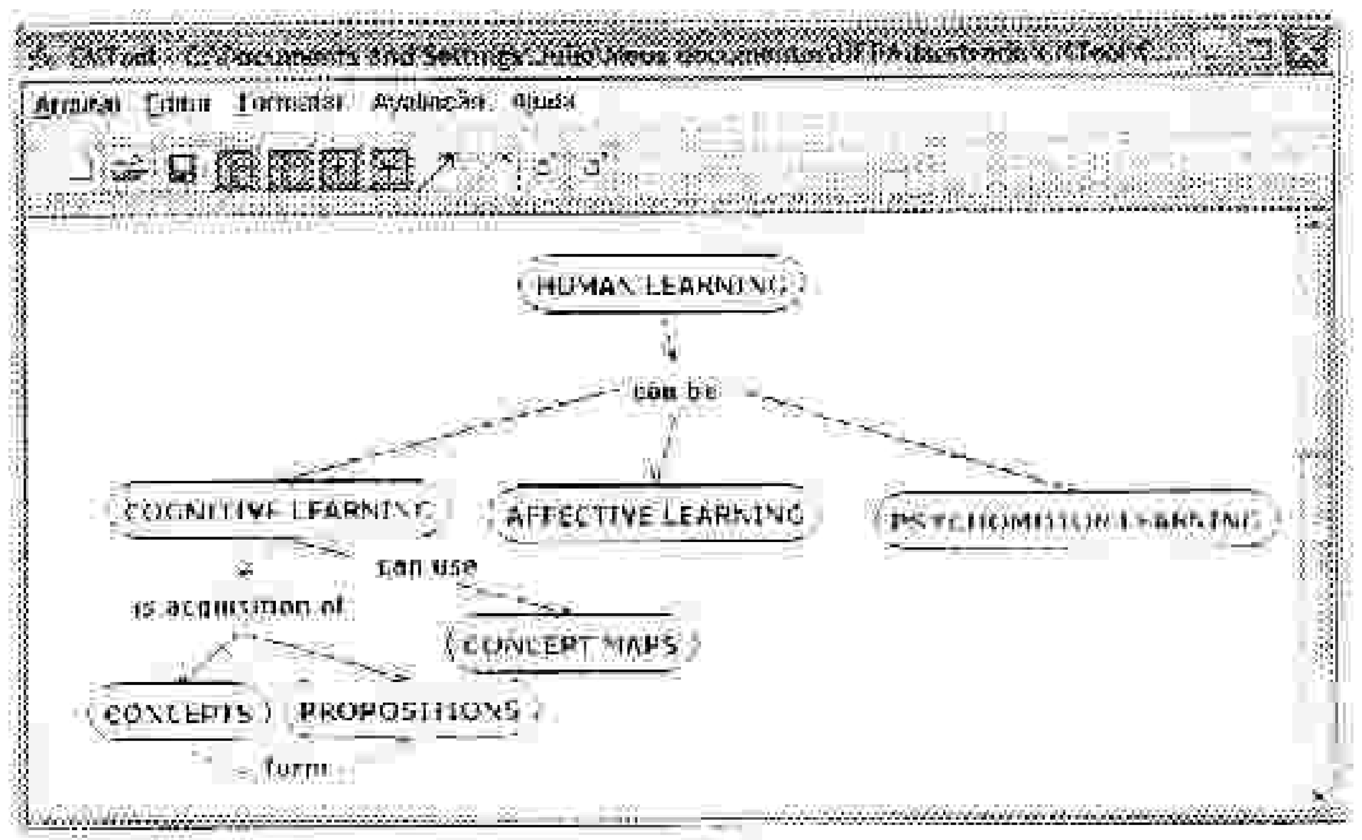

Figure 1. Concept map about human learning

The hierarchical structure of a CM is based on the concept of inclusivity: a more inclusive concept is one that, according to the learning task in progress, can be considered a superordinate concept, i.e., one capable of classifying other concepts in a semantic dimension (e.g. partition, is-a, etc.). The linking phrases used to label propositions are instances of these semantic dimensions (DA COSTA Jr., ROCHA & FAVERO, 2004). Progressive differentiation and integrative reconciliation are also represented in CMs. Progressive differentiation is the process of meaningful learning in which learners increase the degree of elaboration of a concept as they increase their knowledge about it (AUSUBEL, 2000). In order to detect progressive differentiation in a concept map, it is necessary to observe if more inclusive concepts are related to less inclusive concepts in certain dimensions. In Figure 1, the concept <COGNITIVE LEARNING> is progressively differentiated.

Integrative reconciliation, on the other hand, occurs when the learner identifies dimensions of relationships between components not previously connected. In superordinate integrative reconciliation, the learner identifies a more inclusive concept not initially present in the map or not initially connected to the less inclusive concepts. Combinatorial integrative reconciliation happens when the learner perceives dimensions of relationships between concepts that, according to the learning task, are not part of an identifiable hierarchy. The learner does not identify a more inclusive concept, but discerns the need of relating concepts present in different branches of the map. In Figure 1, the proposition <CONCEPTS form PROPOSITIONS> is an example of integrative reconciliation.

CMs are semi-formal knowledge representation tools that use natural language to represent concepts and propositions. As such, they profit from the ease of creation and use: CMs have been used to teach a variety of different disciplines, to many different ages and teaching levels, including kindergarten (MANCINELLI et al., 2004; AFAMASAGA-FUATA'I, 2004). They have also been used as a tool to organize and present information, for course or curriculum development, for navigation support, and for learning assessment (for a thorough discussion on the effectiveness of concept mapping in education, please refer to CAÑAS, COFFEY et al. (2004)). Nevertheless, this ease of use causes an undesirable side effect: ambiguity, which makes it difficult to assess the knowledge expressed in CMs (DA COSTA Jr. et al., 2004).

As mentioned in the previous section, the assessment accomplished through mere comparison of a student's CM and a reference CM is not in accordance with cognitivist principles, as it forces students to construct their knowledge in a way that mimics the knowledge constructed by the teacher or expert who built the reference CM. This approach does not address the fact that humans construct knowledge in a number of different ways. An alternative is to compare students' CMs to populations of CMs generated by some sort of mechanism responsible for building correct CMs based on an ontology.

Our research uses ontologies to generate search spaces of possible correct CMs. These search spaces are then searched by a genetic algorithm (GA), responsible for finding the *best-match CMs*, that is, the CMs in the search space that can be compared to the student's CM. Assessment is accomplished by analyzing the semantic distance between the student's CM and the CMs found by the GA. This is a general approach to learning assessment capable of coping with situations not addressed by the simple comparison of the student's CM to a reference CM. For example, a student who claims that "plants have leaves" will be assessed similarly to another who states that "leaves are part of plants" (synonymy). Another student who states that "plants generate oxygen" will be assessed correctly, even if the ontology contains only the propositions "leaves generate oxygen" and "plants have leaves" (inference).

3 An Overview of CMTool

CMTool is a *mindtool*[1] whose main objective is to help students and teachers to apply cognitivist principles during the learning process. Its block diagram is illustrated in Figure 2. It encompasses seven modules: the administrator, a CM editor, an ontology editor, the assessor, a genetic algorithm, an inference engine, and a repository.

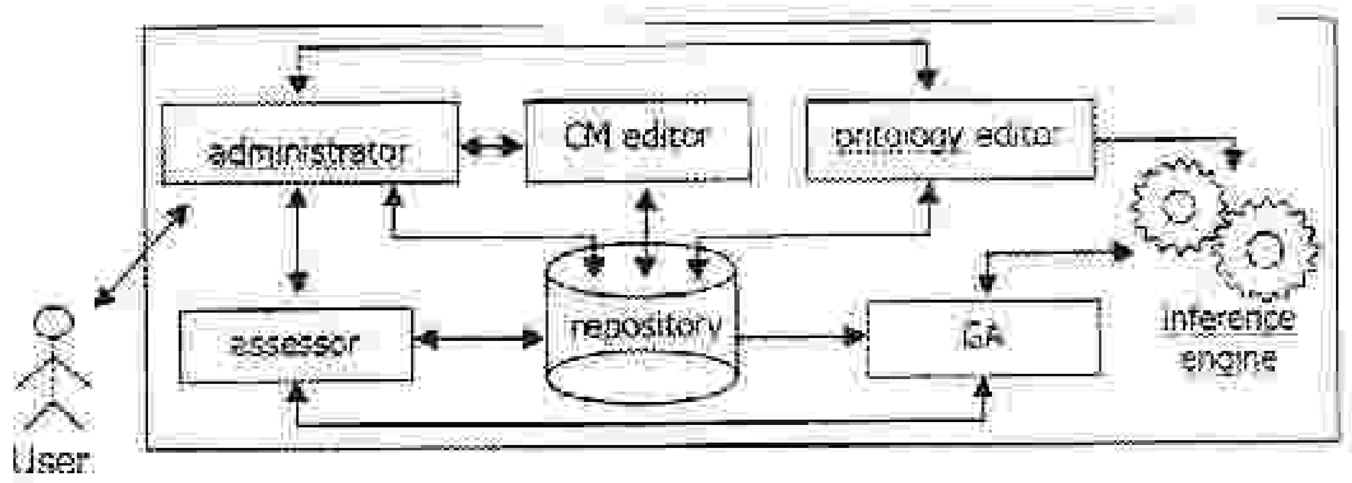

Figure 2. Architecture of the CMTool environment.

The administrator is responsible for controlling environment access. The CM editor implements a visual language for constructing CMs in compliance with the principles of the Assimilation Theory. The ontology editor, called On_Tool, is used to help to construct domain ontologies that correspond to learning tasks. The GA, based on the domain ontology for the task underway, generates populations of CMs, which are used in learning assessment. The inference engine helps the GA in the construction of CMs by analyzing the validity of propositions not explicitly expressed in the ontology. The assessor uses the results generated by the GA to produce a complete assessment of the learning of a student. For details about the assessment model used in CMTool and a description on how the GA works, please refer to ROCHA, DA COSTA Jr. & FAVERO (2004) and ROCHA et al. (2004). The repository contains a taxonomy of linking phrases, user information, instances of search spaces generated by the GA, domain ontologies, and users' CMs. Figure 1 illustrates the CM editor with a CM drawn on its panel.

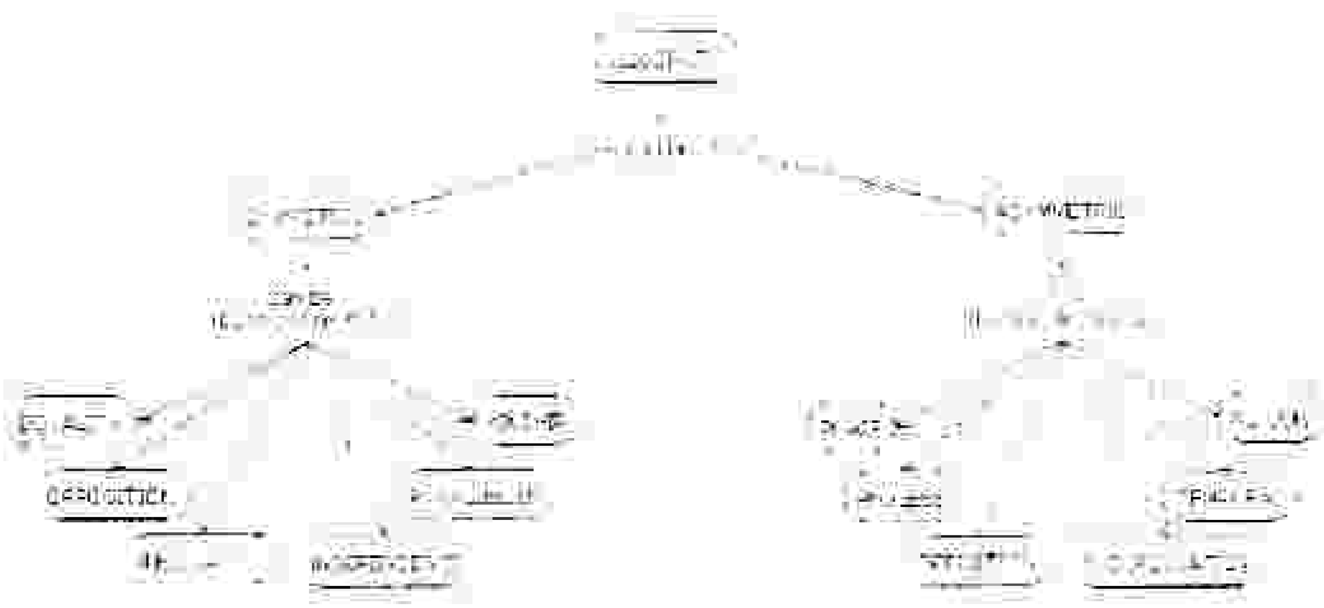

Figure 3. Taxonomy of linking phrases.

Among the various structures and information kept in the repository, one of the most important is the taxonomy of linking phrases. This taxonomy (DA COSTA Jr. et al., 2004) encompasses a model capable of distinguishing between two different propositions and, additionally, capable of assigning a value, called *semantic distance*, proportional to the difference in meaning between the propositions analyzed. The first levels of the taxonomy are illustrated in Figure 3.

4 The Teacher's Role

In accordance with cognitivist principles, the role of teachers in CMTool differs deeply from their role in traditional behaviorist schooling. In Behaviorism, teachers present their conclusive knowledge about the topics of a discipline. It is the students' responsibility to understand these topics the same way teachers do, with little or no opportunity to reinterpret or reconstruct the same knowledge. According to AUSUBEL (2000) and NOVAK (1998), this is a source of difficulty in the process of constructing meanings. Specifically, Ausubel has coined the terms *rote learning* (also known as *mechanical learning*) to designate this kind of learning, emphasizing that it is imprecise, random, and ephemeral in duration. Concerning the results of the learning process, rote learning and meaningful learning are opposite extremities of the same continuum.

In CMTool, teachers are expected to use the environment to help students in their journey towards the construction of their own knowledge. Later on, teachers are expected to assess students' learnings, respecting idiosyncrasies. To help teachers, the environment provides them with a user-friendly tool to create domain ontologies related to the topics of their disciplines. This ontology editor is called On_Tool. The environment also

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encompasses an assessment tool that processes students' concept maps, liberating teachers from the work overload deriving from this task.

In the environment, domain ontologies are used to create common vocabularies for the different topics of a discipline. They are also used to create classification and semantic relationship rules between these concepts, so as to make it possible to infer new knowledge from the knowledge expressed in the ontology and, as a consequence, help in students' automatic learning assessment. Figure 4 illustrates the graphical representation of a domain ontology about data communication, created in On_Tool.

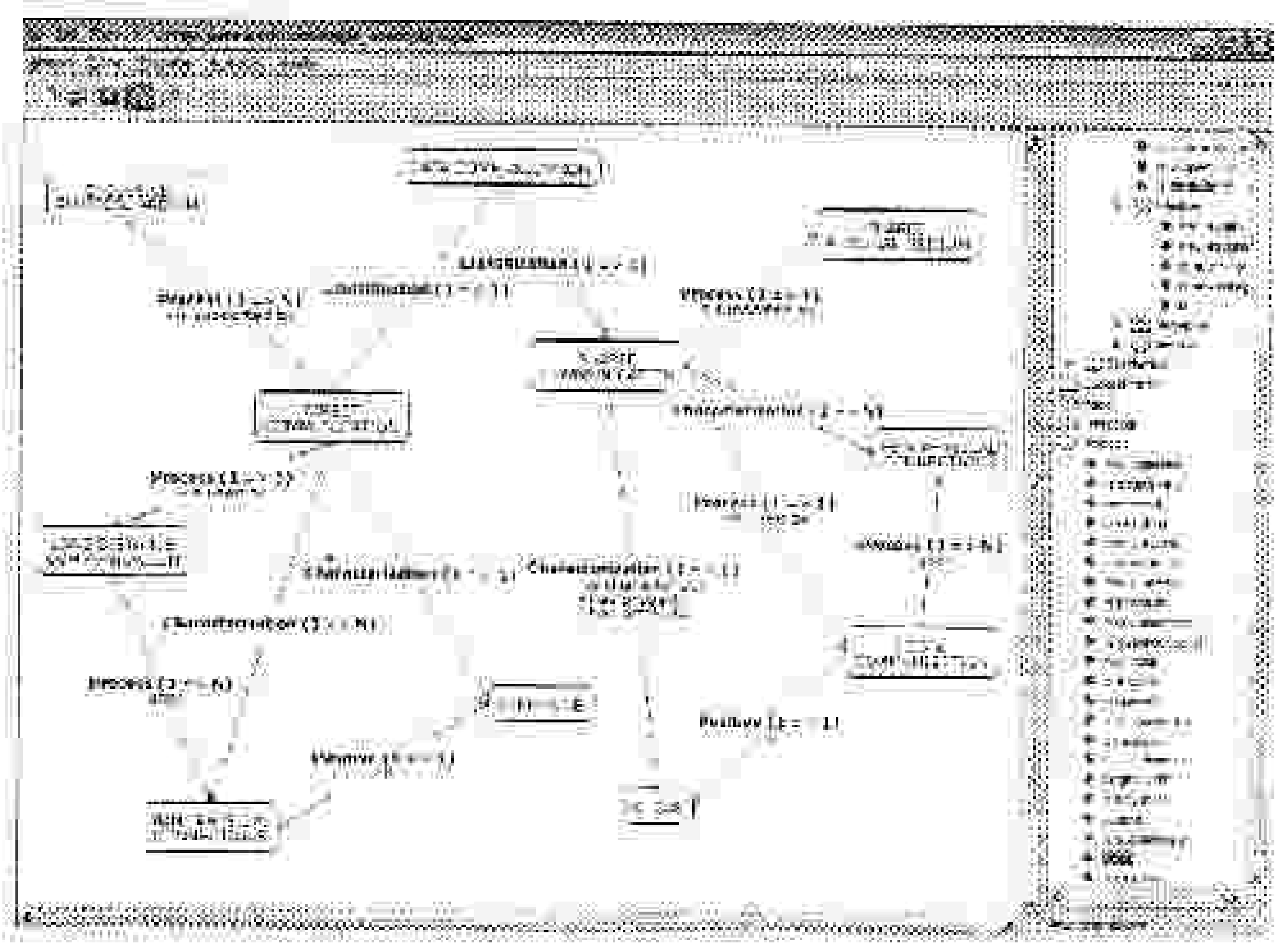

Figure 4. A domain ontology about data communication constructed in On_Tool.

On the right side of the window of On_Tool, it is possible to see the environment's taxonomy of linking phrases. It contains the possible semantic dimensions of relationships between concepts, and the linking phrases that instantiate these dimensions. For example, the semantic dimension *process* can be instantiated by the linking phrases *is used by* or *is supported by*.

As illustrated in Figure 4, when teachers build the ontologies, they are not required to inform linking phrases, but only the semantic dimensions of relationships between concepts. However, in some cases, teachers can limit the linking phrases that can be used in the construction of propositions, in order to improve the accuracy of the CMs generated by the genetic algorithm. As detailed in Section 6, if a student's CM contains the propositions (i) <DIRECT COMMUNICATION has MANY PHYSICAL CONNECTIONS>, (ii) <DIRECT COMMUNICATION is characterized by MANY PHYSICAL CONNECTIONS>, or (iii) <DIRECT COMMUNICATION is not CHEAP>, all of them will be considered valid by the assessment mechanism, because propositions (i) and (ii) denote explicit knowledge (the *characterization* dimension can be validly instantiated by <is characterized by> and <has>), and proposition (iii) denotes knowledge validly inferred from the ontology.

When students construct propositions that cannot be validated by the assessment mechanisms based on the ontology, teachers are notified by the environment, as this event can denote the occurrence of valid propositions not expressed in – and not inferable from – the ontology. As a consequence, teachers can begin a negotiation process with students (mediated by the environment), so as to reach an agreement about the validity of the suggested proposition. If the validity is confirmed, the environment inserts the proposition in the ontology, with the teachers' acknowledgment. The result of this process is the joint development of the ontology, with teacher and students contributing in the negotiation and solidification of concepts.

5 The Student's Role

In CMTool, in accordance with the cognitivist view of meaningful learning, students construct their knowledge by establishing semantic connections between the concepts related to the study of a specific topic of a discipline (these concepts were chosen by the teacher during ontology construction). They construct their concept maps by the continued application of progressive differentiation and integrative reconciliation. The idiosyncratic knowledge represented in the CMs can then be submitted to the environment for learning assessment.

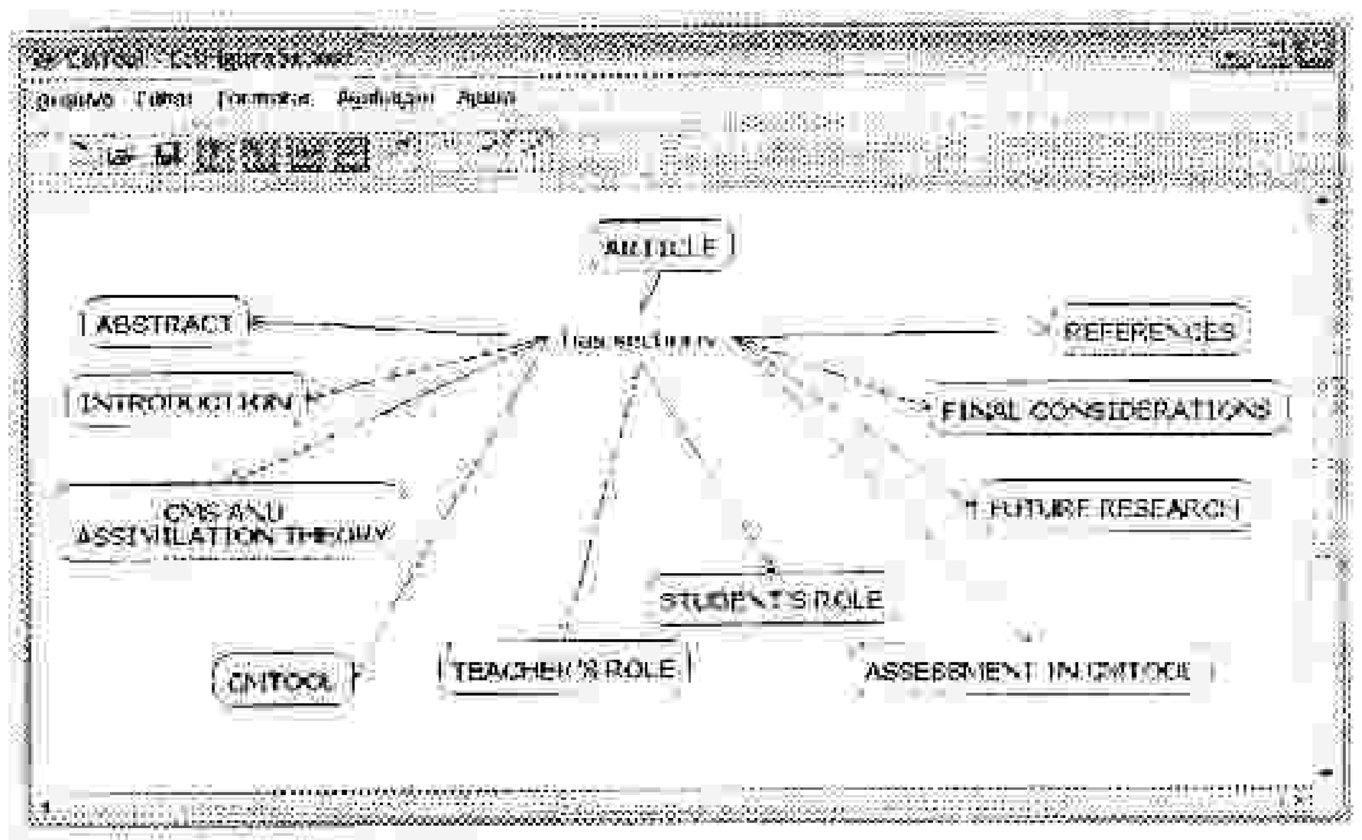

Figure 5(a). A context-free CM.

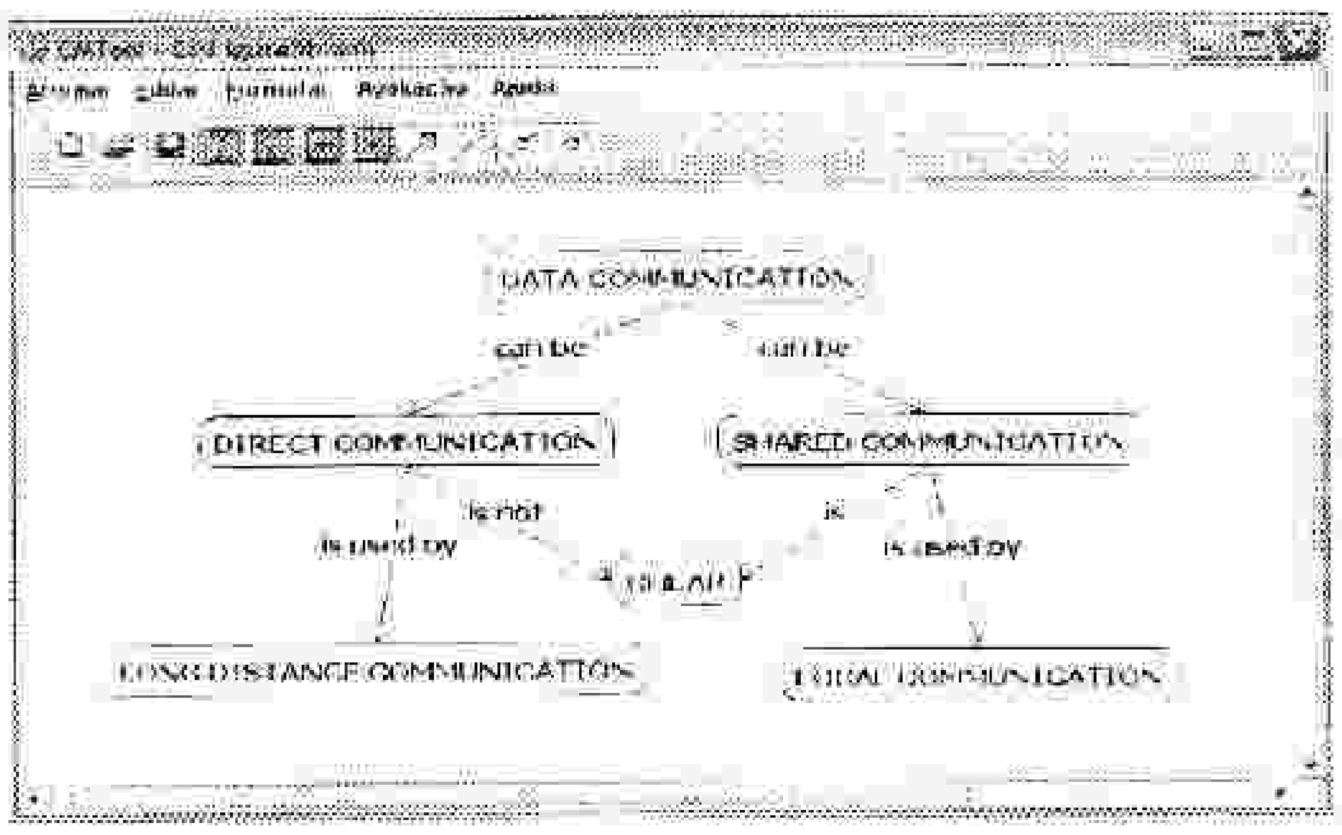

Figure 5(b). A contextualized CM.

In order to help students, the environment provides a CM editor that allows for the construction of context-free maps (designed, for example, to guide a writing activity), as well as contextualized maps. The last ones use the concepts of an ontology stored in the repository of the environment, and can be submitted to the assessment mechanism. Figure 5(a) illustrates a context-free CM used to guide the writing of this paper. Figure 5(b) presents a contextualized CM built from the concepts of the ontology illustrated in Figure 4. The construction processes of these kinds of CMs differ considerably.

To construct the CM of Figure 5(a), only the drawing capabilities of the CM editor were used. This CM represents our ideas about the sections of this paper. Figure 5(b), on the other hand, illustrates a CM constructed in the context of the ontology depicted in Figure 4. As a consequence, the environment restricted the choice of concepts that could appear in the CM. This CM represents a student's understanding of the topic, and can be submitted to the learning assessment mechanism of the environment.

The intervention of the environment, when a contextualized CM is being built, occurs during the choice of linking phrases, because this is the moment in which mappers explicitly define the meanings they assign to their experience. When a student decides to connect two concepts, he/she must first define the semantic dimension under which these concepts will be connected. This step is crucial, because it is the input for other definitions, like the choice of the most inclusive concept in a proposition, i.e., the concept that will become the subject of the assertion that corresponds to the proposition in the CM.

In Figure 5(b), the student chose to connect the concepts SHARED COMMUNICATION and LOCAL COMMUNICATION with the *process* dimension, and the linking phrase that instantiated this dimension was <is used by>. Under these circumstances, the most inclusive concept is SHARED COMMUNICATION. The student could have chosen another semantic dimension for the relationship between these two concepts as, for example, the *classification* dimension. With this choice, the student would be able to construct the proposition <SHARED COMMUNICATION can be LOCAL COMMUNICATION>. However, this proposition would be considered inaccurate by the assessment mechanism, because it is not supported by the underlying ontology. The dimensions chosen by students are stored internally, as the final CM shows only the linking phrases, for readability purposes.

Several variations of the usage steps described in this section can be made during the learning process. Among other possibilities, it is possible to use interdisciplinary ontologies. It is also possible to contextualize and assess CMs under more than one ontology. Another possibility is to assess CMs produced collaboratively by a group of students, as a result of meaning negotiation among them.

6 Assessment in CMTool

In this section, we present an example that shows the functioning of the GA and of the assessor of the environment. For this learning task, the teacher constructed the ontology illustrated in Figure 4. Consequently, the ontology editor (On_Tool) translated the graphical representation of the ontology to axioms in first-order logic, in order to allow for inferences (and further exploration of the search space by the GA).

Based on the axioms, the GA can generate propositions (using concepts from the ontology and linking phrases from the taxonomy) and ask the ontology if they are valid. Valid propositions are stored for posterior creation of individuals (CMs) in the populations generated by the GA. These individuals are evaluated, and a fitness value is assigned to each one, based on its distance from the student's CM (the GA privileges CMs that use the same concepts and phrases found in the student's CM). The final objective is to find a set of *best-match CMs*: those that are similar to the student's CM and valid according to the ontology.

Figure 6 represents a simulation of the actions of the GA (in the figure, "DT COMM" stands for "Data Communication", "DR COMM" stands for "Direct Communication", and "SH COMM" stands for "Shared Communication"). Figure 6(a) represents the student's CM submitted for assessment. It contains a misconception (<SH COMM, has type, DT COMM>). The GA, based on the ontology, generates propositions (Figure 6(b)), which are evaluated by the inference engine, based on the ontology (invalid propositions are crossed out in Figure 6(b)). Valid propositions are kept for creating populations of CMs. A sample of the initial population is illustrated in Figure 6(c).

Individuals in the population are evaluated according to a fitness function that measures their distance to the student's map (maps similar to the student's are scored highly). Afterwards, the GA selects the best individuals to be the parents of the next population (these individuals are circled in Figure 6(c)). The next generation is created with the propositions (genes) of the parents (parents' genes are illustrated in Figure 6 (d)). A sample of the second generation is illustrated in Figure 6(e). The best individuals of the previous generation are kept in the current generation. As in nature, mutation is allowed with a certain probability. When a mutation occurs, the GA uses a new proposition (formed from the ontology and from the taxonomy, and considered valid by the inference engine). Mutations are an important part of GAs, as they allow for further exploration of the search space, and inhibit premature convergence. A mutation is illustrated in Figure 6(e) (dashed). This process is repeated until a best-match CM is found (circled in Figure 6(e)). The best-match CM is then presented to the student as an alternative to his initial CM.

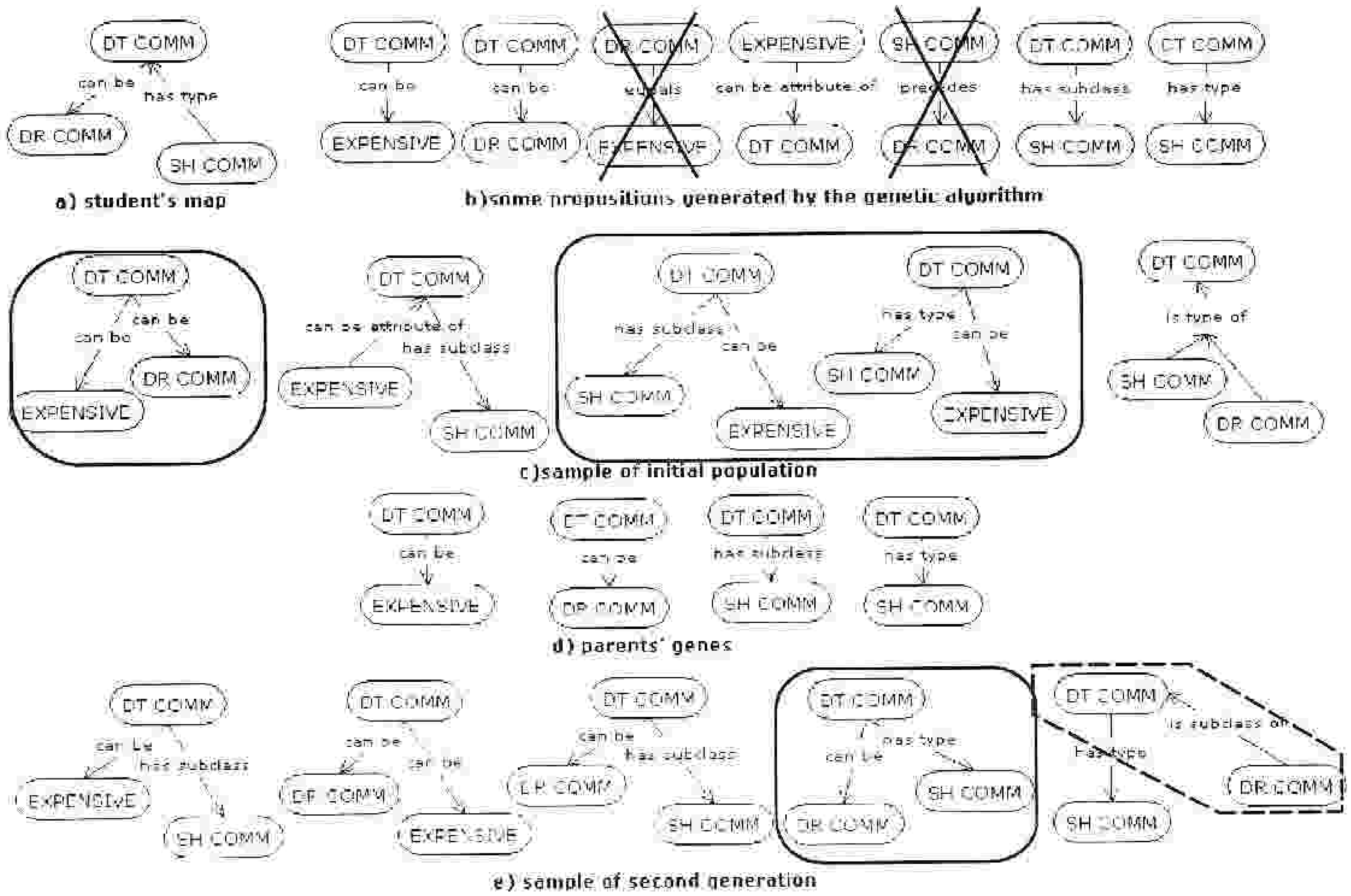

Figure 6. A simulation of the actions of the GA

List 1 presents excerpts of a CM assessment accomplished by CMTool. The results are organized in four parts: (a) Hierarchical structure and learning types demonstrated; (b) Semantic similarity between the assessed CM and the best-match CMs; (c) Actions necessary for the reconstruction of the best-match CMs; (d) Omissions in the assessed CM.

Part (a) reports if the concepts used in the CM submitted for assessment are related to the learning task underway, and if the learner's propositions are valid in the context under analysis. In order to do this, the assessor verifies if the inclusion of the concepts is made through correct relationship dimensions.

Part (b) presents the semantic comparison of the assessed CM to the best-match CMs generated by the GA. The objective is to present to the learner valid forms of mapping the knowledge represented in the ontology of the learning task underway. The assessor calculates the semantic distance between the assessed CM and each one of the best-match CMs. If any of the calculated values is different from zero, detailed information containing the possible alternatives to the identified misconception are presented to the learner.

Part (c) details the actions taken by the GA to construct the best-match CMs presented in part (b). The objective is to show to learners how to construct forms of knowledge representation alternative to their own (presented in part (a)). Finally, part (d) presents the list of concepts that, although present in the domain ontology, were not used by the learner. The list indicates the need for reinforcement of specific topics of the discipline.

List 1. Excerpts of a CM assessment accomplished by CMTool.

Assessment Results
a) Hierarchical Structure and Learning Types
1. Assessed CM:{<DT COMM,can be,DR COMM>,<SH COMM,has type,DT COMM>}
1.1. Concepts: { DT COMM, DR COMM, SH COMM}
1.2. Propositions: p1=< DT COMM, can be, DR COMM >, p2=<SH COMM, has type, DT COMM >
1.3. Valid Hierarchies: {<DT COMM,Asymmetric.Definition.Synthetical.Classification,DR COMM >}
1.4. Invalid Hierarchies: {<SH COMM,Asymmetric.Definition.Synthetical.Classification,DT COMM >}
1.5. Valid Propositions: P1=<DT COMM,can be,DR COMM>
1.6. Invalid Propositions: P2=<SH COMM,has type,DT COMM>
b) Semantic Analysis
1. Best-Match CMs Generated by the GA: CM1={<DT COMM,can be,DR COMM>,<DT COMM,has type,SH COMM>}
1.1. Concepts: CM1 ⊂ { DT COMM, DR COMM, SH COMM}
1.2. Propositions: CM1 ⊂ {p1=<DT COMM,can be,DR COMM>, p2=<DT COMM, has type, SH COMM>}
c) Actions for the Reconstruction of the Best-Match CMs
CM1: Create propositions p1, p2 Combine propositions p1, p2 (differentiate <DT COMM> progressively)
d) Ontology Concepts Absent in Assessed CM
EXCLUSIVE PHYSICAL MEDIUM, LONG DISTANCE COMMUNICATION, MANY PHYSICAL CONNECTIONS, EXPENSIVE, CHEAP, SHARED PHYSICAL MEDIUM, FEW PHYSICAL CONNECTIONS, LOCAL COMMUNICATION

7 Future Research

There are many points of interest for future research, which can help to enhance the general performance of CMTool. Concerning content presentation and assessment, future developments are: (i) automatic sequencing of course material, mainly for distance learning, (ii) automatic generation of questions/answers based on semantic dimensions of relationships between concepts and (iii) automatic searching of learning paths in the ontologies based on their subjacent graphs.

An additional requirement to be satisfied by On_Tool is the automatic generation of axioms for non-trivial types of conceptual relationships. CMTool's taxonomy of linking phrases contains many semantic dimensions in which concepts can be related (e.g. place, process, temporal), some of which are not automatically axiomatized by On_Tool. A future development, thus, is to extend On_Tool's automatic axiomatization capability, in order to improve the inference mechanism and, as a result, increase accuracy in searches.

To help the teaching/learning of procedural knowledge, in parallel with conceptual knowledge, we regard adding knowledge bases (KBs) to the repository of CMTool. These KBs could store artifacts such as illustrations, pieces of code, games, best-practices in the teaching of specific discipli-nes, simulations, etc. Each of these artifacts would be linked to an ontology (or parts of ontologies). This would allow for collaborative activities and guided group discussions on topics of different disciplines. KBs connected to the ontologies would also be susceptible to searching.

8 Final Considerations

In this article we presented CMTool, a learning environment designed to comply with cognitivist principles. Concerning learning assessment via CMs, we found out that the dominant idea is to compare students' CMs with a reference CM. This approach is not efficient, as it does not take into account idiosyncratic forms of knowledge construction. As an alternative to this approach, we developed a GA capable of generating families of CMs based on ontologies inserted by teachers.

It could be argued that our approach works only with very specific ontologies. In fact, the contrary is true. The AG is based on mathematical axioms, which can be applied to any ontology built in the framework of the Assimilation Theory. Ontologies generated by On_Tool are internally represented in first-order logic. This facilitates the sharing and exchange of knowledge represented in the ontologies, and also makes it possible to translate them to other representation languages. Additionally, the proposal for automatic sequencing and exercise generation will be based on general algorithms that can be applied to any ontology compliant with the requirements for educational use.

We understand our approach is a positive step in the automation of practices supported by the Assimilation Theory. The goal of this article was to present CMTool, and illustrate how it can be used to support a cognitivist approach to teaching/learning. We are aware that several enhancements can be made and our next goal is to address these enhancements.

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[1] According to JONASSEN (1996), *mindtool* is educational software whose use leads students to constructivist learning practices and to the development of critical thinking about the topic being learned.

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